THIS PUZZLING PLANET

Edwin Tenney Brewster

4.5

To Dr. Hugh T. Patrick
with the regards of
Robert W. Sayles

ASTRONOMY

See cuts on p. 268 and 282

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on Mass
8-1928
Anniversary

THIS PUZZLING PLANET

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GRAND CANYON OF THE COLORADO

In the foreground, stratified rocks of Paleozoic age and younger, cut through by the river into the underlying Pre-Cambrian. On the skyline, the nearly flat upland. A young valley.

Photograph by the United States Geological Survey

This Puzzling Planet

The Earth's Unfinished Story; How Men Have Read It in the Past, and How the Wayfarer May Read It Now

By

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ILLUSTRATED

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"Nothing—not the wind that blows
Was more unstable than the crust of earth."

ALFRED NOYES.

PREFACE

For so very large an object, the earth gets curiously little attention nowadays from the amateur of natural history. Most men know something of building materials. Most women have an interest in cut gems. All children have been put through an absurd and most uninteresting course in what they are too apt to designate as "G'ography." Some people still walk over the hills. But in general the public is not interested in the earth.

And yet, on the face of things, the study of earth-science might well be the first concern of the amateur naturalist. Its materials are always at hand—mountain crag and rustic glen, railway cutting, cellar hole. One can not look anywhere without seeing the bones of the earth. Moreover, other dilettanti must spy out their material, dry it in presses, store it in bottles, arrange it in cabinets. The geologist, on a journey, has only to flatten his nose against his car window to attain whole days of delight. Altogether, for many reasons, if one is to take up any branch of science purely for the interest and joy of it, then our present-day geology is one of the likely spots.

The reason why, in spite of all this advantage, earth-science has so little amateur following is probably that it is—one must confess—a little difficult just at the start. The attractive feature of, for example, the study of birds and flowers, is always that they can be taken a bit at a time. One begins by learning to tell a crow from a robin, or a rose-bush at sight. Then one advances to the sparrow and the buttercup. Step by step, he goes forward as the spirit moves.

But sciences like geology and physics and chemistry and some others are different. These are no step-by-step affairs, but closely knit and highly theoretical disciplines. It is, indeed, not quite true that "one understands nothing till he has learned it all." Yet each science of this type does hang all together like a cross-word puzzle. The parts interlock. One does not, at the beginning, seem to be making head or tail to anything.

On the other hand, if one is willing to be patient with himself, in time, rather suddenly, things begin to drop into place. One begins to see, behind the endless confusion of detail, a few great, simple processes of nature, that go on, age after age, "without haste and without rest." It is the eye for these, underneath the detail, that the amateur of geology is to cultivate. Then shall he look with his mind's eye into the earth as if it were a

transparent ball. Then shall he behold geologic time stretch out into past and future; and know the soul-stretching reward which comes indeed to every one who has

". . . looked on those wild miracles,
The birds and flowers of earth,"

but comes even more to him who looks upon the earth itself.

In other words, geologic theory is essential to an interest in geologic fact. The problem is to get at the theory by the easiest end; and so pass, as quickly as possible, to that first-hand observation of nature as one walks and travels, which is always the final reward of an amateur interest in any branch of natural history. But for most persons, the easiest approach to any complicated matter is by way of its history. By way, then, of the story of the rise and alteration and decay of various geologic theories, does one come most readily to notice and to understand a thousand interesting or practical matters that all of us are bound to encounter anyway as we knock about in the earth.

Moreover, the story of geological discovery is itself, merely as a story, by no means the least interesting portion of the history of mankind. Men began in Babylon and Egypt to notice the earth about them and to speculate on its structure and

history so far back in time that the beginnings of the Christian Era are nearer to our day than to theirs. It is a long story, and a story well worth telling yet again, how men gradually straightened out the general lay of the cosmos in Athens and Alexandria before most of Europe was, lost their knowledge in large part after the fall of Rome, and picked it up again after the European colonies in North America were well under way. Many an interesting personality had his part in the long tale. Our own countrymen here in the United States have done in this field of geology and geography some of the best scientific work that has been done by anybody anywhere on this side of the Atlantic Ocean. That part, also, one should know about.

Besides, there is North America itself, that has in it some of the most remarkable geologic and geographic phenomena to be seen anywhere on earth—and nobody on earth, on the whole, travels about and sees things so freely nowadays as we do.

The history of geology-geography being, then, no small part of the intellectual history of our own people for three thousand years, is to be read partly in books and partly in the rocks. No man can understand what is in the books, unless he knows something of what the rocks have said. The easiest

way, by far, to understand what the rocks have to tell in the United States of North America is to know something out of books of what the same sort of rocks, in southern Europe and western Asia and northern Africa told our forefathers, a hundred and a thousand and two thousand years ago.

I mix, therefore, unblushingly, in this volume, field-observation, history, and biography. As we all, proverbially, make one hand wash the other, I trust each of my three elements to help out the interest and the understanding of the other two.

This book is a companion volume to my earlier, *Creation: a History of Non-Evolutionary Theories,* which takes up past opinion concerning the organic world in just about the same fashion as this the inorganic. There is, inevitably, between the two, a small amount of overlap by way of fossils. But the two works are nearly independent. Together, they cover the general history of men's ideas concerning the world itself and its living inhabitants. In each, I ask my reader to look about him at animals and plants and rocks and men, and then to interpret what he sees in the light of what other men in the past have thought concerning these same objects, to the end that he may the more easily comprehend what other men think about them now.

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THIS PUZZLING PLANET

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CHAPTER I

SHEPHERD AGAINST SAILOR

One doesn't like to think that his ideas concerning this strange universe into which each of us is unexpectedly thrust, his notions of the true, the beautiful, and the good, his vision of his duty to God, are all more or less colored by the quality of the dirt under his feet, even when that lowly earth does not altogether determine some of them. Still less does one like to be reminded that the ideas that he thinks are his own are really not his at all, but mostly the opinions of ancient worthies, dead these thousand and two thousand and three thousand years—which opinions in their turn rest not a little on the sorts of rocks that were the hillsides over which wandered long-departed flocks, the soil of ancient river-bottoms where men first planted crops, or headlands past which long-forgotten sailormen steered fragile boats.

Yet such is, to no small degree, the fact. Our ultimate ideas of the nature of things and what we ought to do about it all, and in particular our theological and our scientific ideas, come largely either out of ancient Greece or ancient Israel. Greece and Israel, in their turn, lean on Egypt and Babylonia. What, therefore, the east end of the Mediterranean thought during the last thousand years of pre-Christian time, colors deeply what we think and do now.

But what Greece and Israel and Egypt and Babylon thought hung partly on what they saw. Therefore does the fact that Egypt and Babylon are dry countries on a flood-plain, and Greece and Israel rainy districts in the hills—along with various other characteristics of both—affect profoundly the course of European thinking through more than two millennia, and determine, much more than we either realize or admit, certain highly important notions that men now hold.

The pit out of which our present-day civilization was dug was, in short, that long-civilized Mediterranean country from the Pillars of Hercules eastward to Mesopotamia and the Persian Gulf, southward to the limits of Upper Egypt, and northward as far into the Alps and beyond them as our fathers after the spirit had enterprise or curios-

ity to go. That district is for us the Ancient World. What there is in it, our forebears saw. What they saw, they thought about. What they thought, they passed along to us. Just that, in large measure, is what we think now.

We must not forget—prone as we are to do so—that these fathers of ours of a thousand years or so before our era began, were men like ourselves, equally intelligent, equally ingenious, equally curious. But they did not, for the most part, have books to read, nor most of our ways of killing time; and they did not have any sort of artificial light that gave them much chance at either work or play after dusk. Therefore—partly, one guesses, to avoid being bored—they did on the whole rather more thinking than we do now; and they thought much about the stars and the rocks.

The Babylonians went in especially for astronomy, for they had a dry climate, a free horizon, and a clear sky. They gave us much of our magic and most of our astrology, the three hundred and sixty degrees of the circle and the sixty minutes of the hour, the signs of the zodiac, our week of seven days, after the seven planets—which we, however, call mostly by their Roman names.

But the Babylonians did not geologize. "Syria of the Rivers," as the Hebrew calls it, is a flat

country, the great flood-plain of the Tigris-Euphrates, a quarter-thousand miles wide, where the river silt has buried far out of sight and mind all the hard and interesting older rocks. There is really no getting up geology out of a mud-flat. That takes mountains.

To be sure, there are high mountains up-stream from Babylon—Ararat where the Ark stranded, and the "Mountain of the North" behind which the sun was thought to hide himself by night, on whose top was the Garden of Eden. But the Babylonians were a race of Babbitts, who dwelt in cities and did business, oppressed weaker peoples, and cultivated—not inefficiently—the more sedentary sciences. They did not go to and fro in the earth, sailing and exploring and climbing mountains. Therefore, had the Babylonians no geology.

Therefore, also, had the Hebrews none. They borrowed all their science, most of it from farther east, having themselves no heads at all for any sort of natural knowledge; and no Jew seems ever to have noticed that the mountains which are round about Jerusalem are stratified rocks. Old Testament and New alike are crammed with astronomical allusions—but neither has a hint of any earth-science. There is no geology in the Bible for the same reason that Nineveh is builded of brick instead of marble.

Picture, therefore, Israel of the Exile, seated by the waters of Babylon, hanging its harps upon the willows, wailing for a lost Jerusalem; but when it had a chance to go home, promptly, for the most part, forgetting Zion and staying in comfort where it was.

The remnant that did return, rigidly selected for religion, brought back for science only what it had learned in Babylon. It had its vision of the changeless stars that circle the sky without haste and without rest, and of an Ancient of Days who created the stars in the beginning, who also does not change. That is what men of genius in the field of religion learn in a flat country with a clear sky, where nothing alters, and nothing is especially varied or interesting. So the Jews brought back from Babylon the beginnings of three leading religions of the world to come, colored with the hue of the desert. They knew astronomy, and so far as their science affected their religion, it was the stars and not the earth that gave the twist. They knew no geology, because the hard rocks of Mesopotamia are a hundred feet down where nobody can see them, under the great flood-plain. The Jews, therefore, with ourselves and Islam after them, missed the quite different twist which an acquaintance with the rocks gives to a religion or philosophy.

Not so the ancient Greeks. Theirs is a rough country, both varied and interesting, out of which they quarried marble and dug metals. They also were sailormen and travelers, and they had such a native bent for natural science as no peoples have had before or since.

Now geology is a somewhat peculiar field of knowledge. It does not, as many sciences do, progress almost altogether because some uncommonly able man has a flash of insight, or puts in years of hard thinking, or piles up and analyzes complicated evidence. All this does, of course, happen in earth-science as in other fields. But the earth, unlike various of its parts, has a way of answering its own questions. Wise men wrestle vainly with an unsolved problem. Then somebody, only moderately wise, just by knocking round the world, happens upon the particular spot where the evidence is spread out most simply and clearly, for any man with his eyes open to read directly out of the stone book. The toothed birds of the Jurassic, for example, rest on two fossils only, which might easily never have been discovered. There is but one Heidelberg jaw. The United States Geological Survey, working over the semi-deserts of Utah and Arizona, read a whole new volume of Earth's history that grass and trees had quite concealed in

Europe and the East. So the Greeks who were born sailors were the first geologists. After them, have come the British. Both have been able, impatient amateurs.

Two things, then, about the rocks the ancient world saw clearly. Two things the alert and open-minded Greeks in particular interpreted in the only reasonable way.

The plums in a pudding-stone are obviously the water-rounded pebbles of old strands; the dough between them is obviously sand.

One sees a pudding-stone outcropping in the hillside or built into some work of man's hands. The pebbles are the size of one's thumb, or the size of one's two fists, or variously of any size between; and they are of all sorts and kinds and colors mixed in together without rime, but with obvious reason. One also walks a present-day pebble beach, and there is exactly the same thing—the rounded water-worn pebbles not too different in size, of all sorts of rock. And every time the wave breaks, one hears the pebbles grind on one another, rounding each other off, wearing each other down to sand and clay. The pudding-stone is now hard rock—so hard that, ofttimes a crack will run straight through a pebble in it, instead of following round the old surface, so that around Boston for example the

"Roxbury Conglomerate," of the Coal Period, is the best of the local building stones. But nobody can look at a modern pebble beach and then look at an ancient pudding-stone without seeing, plain as the nose on his face, that the two are the same thing.

So is it also with the sandstones. One notes the sea beaches, the sand-bars in the rivers, the silt left by the spring floods. Then one turns to his own brownstone front, the steps that go up to his door, the sills and window trimmings of his town hall, the carved stonework of his church interior. Some of these may be granite. But mostly they will be sandstone. And when they are sandstone, they will be exactly like, in each minutest detail, to the loose familiar sands of beach and dune and bar.

The finer grained "mudstones"—the shales and slates and chalks and limestones—speak with the same voice. One sees the mud-flats at low tide. There is the soft ooze drying in the sun, building up little by little each year as more mud settles over it, until in these late days many an old harbor, where colonial ships landed cargoes at wharves, is silted up and useless.

One sees on such a mud-flat all sorts of things besides mud—clams six inches down; snails on the

A Pudding-Stone

Formed by cementing a beach gravel. Paleozoic. Olean, New York.

Palezoic Limestone with Fossil Brachiopods

Platteville, Wisconsin

Photographs by G. F. Morgan

surface; patches of grass sticking out, with their characteristic animal inhabitants; footprints of wading or flying birds; with prints of rain-drops, also, and ripple-marks.

Then one turns to a slate quarry, to the flagstones of his sidewalk, to the hill that is being taken down, to the cellar hole in the next street, to hillside and gorge and glen. There is the same thing—now solid rock. There are the ripple-marks and the rain-prints. There are the mollusk shells. There are the footprints—dinosaurs, to be sure, more commonly than birds—and the tracks where worm or trilobite or mollusk have dragged themselves across the mud, with sometimes between the paper-thin layers of a shale the fragments of an insect or a scorpion that flew or crawled or floated too far from shore to get back alive.

The old shales and slates and limestones, moreover, sometimes contain remains of fish—teeth rather commonly, and the dense ear-bones that resist decay. Besides, there are sometimes whole fish bodies, the flesh carbonized, the bones petrified, but even the fin-rays and the scales still outlined, so that certain ancient fish, long extinct, are known almost in as much detail as living ones.

Occasionally, a whole school of small fry has been caught in a tidal pool or stranded on a sand

flat when the wind changed, or killed by an earthquake shock or poisoned by volcanic gases, all just as happens now. Often a whole colony of helpless shelled creatures has been overwhelmed by the shifting of beach or bar in some Paleozoic storm. In various such ways a rock layer becomes packed locally with animal remains. Still, as a whole, barring snails and clams and brachiopods, animal remains in the rocks are vastly less common than the unscientific world thinks or the scientific world could wish, and of plants, outside the coal, science knows still less.

Now it so happens that the ancient Mediterranean world where all our own history starts is pretty much all a district of just these puddingstones and sandstones and shales and slates and limestones, that are so very obviously nothing more or less than our pebble beaches and gravel-bars and sand-banks and deltas and mud-flats of the human period hardened into stone, that is sometimes very hard and sometimes only just a little harder than the loose material to which it so evidently corresponds. Europe, fortunately, with northern Africa and western Asia, is for the most part a region of stratified rocks, generally about horizontal, not much altered from their original condition, and altogether so obviously nothing but indurated

sand and mud and gravel, that all ancient people who had the least interest in understanding the reason of things seem to have jumped at once to the conclusion that what these stratified rocks seem to be, that they actually are.

The Hebrews did not do this, because they had no interest in nature except what they took at second hand. The Mesopotamians did not, because their stratified rocks do not show. But the Hindus did, and the Egyptians, and still more those alert and curious Greeks who always saw everything in sight and always wanted to explain everything they saw.

There, then, was the first thing that the Greeks and others saw at the beginning of geological science—that the stratified rocks of Greece itself and of all the country, east and west and north and south, as far as their ships sailed and their armies marched, are everywhere like, to each least detail, all the various deposits that the rivers and the sea are making all the while. They saw what was under their eyes. They put on it the only possible common-sense interpretation.

CHAPTER II

THIS NORTH AMERICA OF OURS

One studies history most sympathetically—one reads biography most profitably as well—if one does also a bit of play-acting. Here was our ancient worthy, a man like ourselves, with a wife and children, tools and dwelling, and his living to get. He was, besides, set in a landscape, with weather, just as we are now, except that for the most part he did not try to level off his landscape, up-root his ornamental plants, cut off his woods, or otherwise spoil his scenery, and he could not control his weather by turning on the steam. All men, in short, have looked out on a landscape and noticed what there was to see. One understands ancient men, in part, by trying to imagine oneself in their sandals looking out over their hills.

Fortunately for this little flight of imagination, all the world is a good deal alike. At least, we here in North America, with a fair amount of traveling about, can see for ourselves, with our own eyes, just about all the different sorts of country that our

Mediterranean forebears observed, when if the world itself was not young, all natural science certainly was.

For purposes of the amateur of the landscape and the rocks that make it, this North America of ours divides itself most naturally into two parts.

After Miller in *Historical Geology*. Courtesy of D. Van Nostrand Company.

THE CANADIAN SHIELD AND ITS OUTLIERS
These rocks are among the oldest of the world.

One of these is the so-called Canadian Shield with its outliers, that include among them rather less than half the area of the continent; where, speaking broadly, there are no proper stratified rocks. The other is the remainder of the continent, where, speaking more broadly still, there is not much else. One's ideas of what rocks are like turns a good deal on which of these two districts happened to be his boyhood home.

The Canadian Shield has its central boss somewhere in the north part of Hudson Bay. One might, in fact, to carry out the figure, say that Southampton Island, that is a hundred-odd miles across and helps to close the mouth of that great inland sea in which Henry Hudson's sailors turned him adrift when North America was first being explored, is the conventional knob which most ancient fighting-men put in the middle of their bucklers. From Southampton Island, then, the Canadian Shield extends southeast to the edge of the St. Lawrence Valley, southward to Lake Superior, southwest to Lake Winnipeg, and northward to include that half-explored and quite unnamed archipelago that lies north of the continent beyond the Arctic Circle. Northeastward the Shield includes all the southern half of Greenland. By way of Iceland, the same sort of rocks connect

across with the Scotch Highlands and the mountains of Scandinavia.

Those are very old rocks, as old as any on earth. And because they are so very old, everything has happened to them, many times over, that can possibly happen anywhere. The rocks of the Canadian Shield, therefore, are everywhere twisted and broken, heated over and recrystallized, squeezed into layers, drawn out into ribbons, intruded by liquid granites and lavas that have first frozen in place and then been mashed and altered endlessly in the long ages since the beginning of known geologic time. The fossils are nearly all destroyed, and the old layers are as likely to stand on end or be upside down as in more conventional positions.

These rocks form, then, a "basement complex," that probably really extends all over the entire earth underneath everything else. In fact, there are patches in view here and there almost everywhere; the Colorado Canyon, for example, cuts down into it. But the complex is so very complicated that if the ancient Mediterranean district where men first took to studying the rocks had been like the Canadian Shield, it is difficult to see how geologic science could ever have got started at all.

An outlier of this Canadian Shield makes up

more than half of New England, mostly in New Hampshire and Maine. Through this district, the hills are apt to be granite, but all through the lowlands, in the sea-cliffs and along the roadways, one sees patches, often miles across, of this very ancient rock, everywhere so much mashed and altered that one can at best only just make out what sort of ordinary rock this old "complex" must once have been. Practically, out of this sort of thing, no human being could ever hope to make any beginning at geology.

There is another such outlier of the Canadian Shield, not so large, that includes the Adirondack region just west of the Hudson-Champlain Valley; and still another, about the same size, say a hundred-odd miles across, in northern Wisconsin, just south of the west half of Lake Superior. There are also smaller, very irregular patches of the same very old rock in the western mountains from Colorado and Wyoming to the Pacific Ocean and northward into British Columbia. But any great mountain system is a mixed-up mess in which almost anything may turn up anywhere.

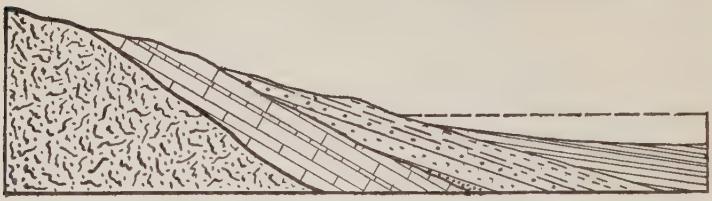
An especially interesting mass of these "Archean" rocks forms the Piedmont Belt of the South Atlantic States, from Maryland southwest, a hundred miles wide, through Virginia, the Carolinas

and Georgia, to end just short of Montgomery, Alabama.

This Piedmont Belt is really the western edge of the ancient and long-lost continent of Appalachia, which before the geologic record in detail begins, lay out in what is now the Atlantic Ocean, and quite probably either extended or connected across to Europe. At any rate, it must have been a big affair, and it must have carried many high mountains, because the wash from it formed the strata which are now the Appalachian Mountains and the whole district westward almost to the Mississippi.

It is usually possible to make out by the look of land-wash which way its source lies, because the finer material is carried farthest and the coarser material is toward the old shore. Often, indeed, a veritable sea beach, sand or pebbles originally but now sandstone or conglomerate, locates exactly an ancient strand, and shows precisely where the sea waves beat upon the coast before even the lowest vertebrates had appeared on earth. In addition, rivers can not bring down coarse stuff unless they are swift. They can not be swift, unless they come down out of high mountains. So we know that the lost land of Appalachia was, at times, a high country and a large one, and that it faced a shallow inland sea where most of the United States now is.

Long after the time of the Pennsylvania coal, in fact well along toward the end of the Age of Reptiles and almost up to the beginning of the Age of Mammals, this Appalachian Land tilted downward on its east side, so that the ocean came in over it for something like a hundred miles beyond our present-day Atlantic Coast. Then, of course, the land-wash went the other way; and thus built the coast plain from Long Island southward and



PIEDMONT BELT AND COAST PLAIN OF SOUTHEASTERN UNITED STATES

The greater part of the very ancient land of Appalachia has been tilted downward on the east until only the western border is above water. Later, it has been slowly rising to its present level. The old sea-floors have therefore been coming up as the unconsolidated strata of the Coast Plain, mostly of Cretaceous and Tertiary age. More like them are still forming farther east below tide level. The old and hard rocks of Appalachia form the Piedmont belt. Between the hard rocks and the soft, runs the Fall Line.

around the border of the Gulf of Mexico, until the wash of the present-day Mississippi buries it out of sight.

All this coastal plain is as utterly different as rocks can be from the Piedmont Belt that runs along parallel with it. The one is vastly old, its rocks not only hard but twisted and wrinkled and

altered out of all resemblance to the old sea-floors and lava sheets that they pretty certainly once were. But the other sort is rather obvious sea-floor—sand much of it, with clay and the like, just about the sort of thing that one sees forming now on the beaches or just offshore. One has only to shut his eyes and imagine the shore-line a hundred miles farther northwest, and then to picture the sea slowly retreating and leaving its usual offshore and beach deposits to become dry land, to have the key to half the science of geology. That coastal plain is obvious sea-floor. One sees the layers in it, formed as the ocean backed away and then returned, but on the whole retreated to the present shore.

Most fortunately, much of Mediterranean Europe is just about the same sort of obvious old sea-floor as the great coastal plain of the United States. Much of it, also, is of about the same geologic age. Some of it, to be sure, has been hardened and even made into mountains. But still it remains for the most part, a good deal as when it was first laid down. So the ancient Mediterranean world had always a great geologic object-lesson before its eyes. It saw stratified rocks in the hills that were only a little different from the strata of the lowlands. These in their turn were just about like the

unconsolidated stuff of beach and bar and mud-flat. All Italy is like this. So is most of Greece. Egypt off the Nile flood-plain is the same. So is Asia Minor and the district south through Arabia and Palestine. The ancient and unintelligible rocks of the Old World, such as make up the Piedmont Belt and the Canadian Shield, are away off in the mountains or beyond the Baltic Sea, in China and Central Africa, where the Mediterraneans never saw them at all. That was all very fortunate indeed for the beginnings of geologic science some three millennia ago.

This contrast between the old and hard rocks of our own Piedmont Belt and the new, soft stuff of our coastal plain, brings about a very curious result. The rivers of the South Atlantic States, for the most part, rise in the Appalachian Mountains or the Piedmont Highlands, and flow southeast to the sea. So their upper courses are on hard rocks; their lower, on soft. They form, therefore, falls and rapids in the Piedmont Belt, with resulting water-power. But on the other hand, they dig out wide valleys in the flat soft coastal plain, and are navigable all the way up to the "fall-line," at the edge of the older country, where the streams drop off from hard rocks that they can not wear away, to soft rocks that they both can and do.

Hence, between the water-powers on the one side and the navigable rivers on the other, arise the

Geography Supply Company, Ithaca, New York

THE FALL-LINE AND THE FALL-LINE CITIES

Southeast of the line (stippled) strata of the younger sea-floor, only partially consolidated. To the northwest, a band of the very ancient and very hard rocks of an outlier of the Canadian Shield, which extends southeast under the coast-plain and beneath the present ocean.

"fall-line cities"—Trenton, New Jersey, with various smaller cities farther north; Philadelphia, Baltimore, Washington; lesser places as one likes; Richmond, Petersburg, Raleigh, Columbia, Augusta, Macon, and finally, Montgomery in Alabama, where the border between the old country and the new turns to the northwest and the rivers no more run comfortably down-hill to the Atlantic. It would have made a vast difference both in the political geography and in the history of eastern United States, if that old Appalachian Continent had tilted down on its east side more than it did, or less.

Curiously, there is at least one other lost land, similar to Appalachia, on the west side of North America, that laps over into the present-day Pacific states, and is mostly sunk under the ocean there. But the high mountains on that side of the present continent have so mixed up most signs of the older one that was there once, that the wayfaring man, bent on another errand, can not make out the ancient relations of land and water as he can on the east and along the southern border of the Canadian Shield.

Between the Appalachian Mountains and the Rockies, south of the Canadian Shield east of the Mississippi, and west of it also in Canada, with all

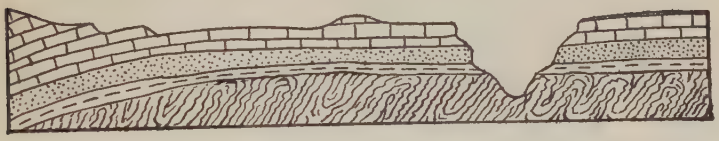
Two Relief Maps Showing Structure of North America

Above: Southern Appalachians through Virginia and Kentucky. On the east, the Pre-Cambrian Piedmont Belt. Center, the Paleozoic rocks of the Appalachian Mountains, much faulted and folded, resting on Pre-Cambrian. Toward the left, these rocks are less and less disturbed until they become horizontal.

Below: The High Plains and the Rocky Mountains along the Canadian Pacific Railway. On the right, the horizontal strata of the Plains cut off by the great overthrust. Center, the much faulted strata of the Rocky Mountains.

Courtesy of *Ward's Natural Science Establishment, Rochester, New York.*

the vast strip of country east of the Rockies from the Dominion to the Gulf, lies a region of typical and commonplace "bread-and-butter" formations—just ordinary plain, stratified rocks, that lie nearly flat and horizontal just about as they must have been formed, and yet are old enough and hard enough, to stand up in cliffs and hills, to keep their shape and texture, and in general to offer



THE COLORADO PLATEAU

At the bottom are pre-Cambrian rocks that formed the old sea-floor on which were laid down the Paleozoic and younger rocks that now appear in the canyon wall. At the left, are still younger rocks that have been removed from the district near the river. An old and nearly flat upland, elevated and cut by a new valley.

themselves for the easiest sort of geologic study. The old rocks of the Canadian Shield are too much messed up to be made out. The youngest rocks of the coastal plain are too vague. But the great interior plain of the United States, together with most of Canada off the Shield, is as if made for the amateur geologist. The same sorts of rocks, of the same periods, do indeed occur also in the great mountain systems; and where they are not too much thrown out of place by the mountain-building processes, the strata are to be made out there also.

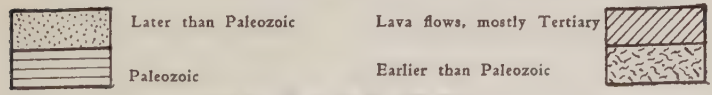
But in general, the easy things to see in North American rocks are in the districts, not too flat, of the great interior plain, from New York across to Wyoming, from the Arctic Ocean to the Gulf.

Just such rocks form the British Isles, France, Germany, and most especially Italy, in which four countries geologic science started over again as European science, three hundred years ago, began to come back again after the fall of Rome a thousand years before. Just such rocks form also Arabia, Persia, and North Africa, where geologic science still kept itself alive through the Dark Ages of Western Europe, and carried over Greek science to our own time. The history of science for the last three centuries could hardly have been what it has been, if the rebirth of civilization had been in eastern Canada instead of Italy.

In a general way, the strata of the interior basin are oldest toward the north and east, and grow younger westward and south. This is, however, true only in the most general way. There is a great patch of rocks in Missouri, where the Ozark Mountains have bowed up the lower strata, that is the same age as those of the St. Lawrence Valley and most of the lowlands of New York. There are like patches somewhat smaller in area in Indiana and Tennessee. On the other hand, there are rocks

in New England and on Prince Edward Island, small areas to be sure, that are younger than anything one encounters on a large scale until one gets west of the Mississippi. Still there is the general rule that the West is young in its geology as in other things.

GEOLOGIC AGE OF THE LARGER AREAS OF THE UNITED STATES



In general, too, the strata tend to slope away from the older spots. The slope is, indeed, very gentle. As one sees the strata in the hillsides, they

look horizontal. But if one follows a layer along ten or twenty miles westward or south, it does most commonly drop down, to pass finally underneath a younger layer—for it is obvious common sense that the older rock layers have to be laid down first, before the younger can form on top of them, a simple principle that persons who ought to know better sometimes neglect.

In New York State, for example, east of Lake Ontario, between that and the Canadian outlier in the Adirondacks, the rocks are Lower Paleozoic, about as old as rocks ever are short of the very old rocks of the Canadian Shield. They dip very gently south—evidently offshore deposits sloping away from the land at least enough to let the ancient sand and mud work away from shore, downhill. South of Lake Ontario, the Silurian comes in, at the upper part of the Lower Paleozoic. East of Lake Erie and across to the Hudson Valley and just over the line into Pennsylvania, the rocks are Devonian, well down in the Upper Paleozoic. In Pennsylvania, comes in the late Paleozoic coal. One picks up the Age of Reptiles in Alabama and North Dakota. The Age of Mammals is spotted over the western country, with vast areas in Nebraska, Kansas, Texas, and New Mexico. Still farther west, one gathers, Men are Men—or at

least, to the west and south appear the oldest important remains of pre-Columbian humanity.

Over all these stratified rocks of whatever age, everywhere north of the Ohio River, lies the "drift," which we now know to be glacial; but which up to the 1840's quite baffled geologic science. Over the other strata, for the most part down toward sea-level, lie the meadows and flood-plains and sea beaches and dunes, that are forming still, as they have formed in like situations throughout known geologic time.

One gets the scale on which geologic processes still go on by reflecting that the Mississippi flood-plain and the Mississippi delta, a sandy shale in embryo, which are both building every year under our eyes, are between them a hundred miles wide and six hundred miles long, from above Cairo in Illinois far out under the waters of the Gulf of Mexico beyond the last straggling bit of Louisiana. There is a continuous sand beach, most of it above water, from New Jersey to Florida, nearly a thousand miles. Some day that may be a sandstone layer in a mountain range. If one counts in ground-up shells along with the sand and ignores certain patches of mud, that beach is continuous for three times this distance, from Cape Cod, that is, well down the east coast of Mexico. The Great

Barrier Reef of Australia, on the way to be limestone, is twelve hundred miles long, and in places a hundred wide.

Nature, in short, still works on the same vast scale that she always has.

CHAPTER III

THE GEOLOGY OF COMMON SENSE

But the Greeks—and with them the Egyptians and the Hindus—went a long step beyond merely seeing that most of the stratified rocks of southern Europe, western Asia, and northern Africa are precisely like present-day beaches and deltas and sea-floors; and therefore, presumably, are really nothing other than ancient beaches and deltas and sea-floors, with fossil water-creatures in them, now hardened into rock, visible in the hills, quarried out for building stone. All these wise and ancient peoples saw also that if rocks, now on land, are old sea-floors, if the fossils in these rocks were once living creatures in the sea, then it follows that the ocean has, at some time or other, occupied most of the districts in which ancient men were interested. The Mediterranean country is mostly stratified rocks. Therefore it follows that most of the Mediterranean country has been under sea.

Aristotle saw this clearly, setting forth in his *Meteorics* not far from 330 B. C., that the dry land

must sink locally at times to let the sea in over it, while parts of the sea-floor rise up and become dry land, so that there is a continual shifting about of land and sea, all quite in the modern way of thinking about such things.

Strabo's *Geography* takes up the same tale, the first encyclopedic geography of the Western World, written about the year 7 B. C., in the great age of Rome, when Augustus Cæsar ruled the known world and Publius Vergilius reclined *"sub tegmine fagi."*

One thinks of Strabo as a Roman, but like many another learned person of his day he wrote in Greek, was in fact of Greek extraction, born in Asia Minor, and his name properly is Strabon. He was a Stoic by conviction, and a man of independent means, as many a great man of science has been before his time and since, the typical gifted amateur. The *Pax Romana* in Strabo's day had made most of the known world safe for everybody; and Strabo spent his life going to and fro in the earth and wandering up and down in it, mapping and recording what he saw, picking up information from other travelers, and reading widely the works of earlier geographers, mostly Greeks—Aristotle, Eratosthenes, Thucydides, Polybius, besides that not unfamiliar tome of Julius Cæsar's concerning

the war in Gaul, on which some half-hundred generations of schoolboys have cut their scholastic teeth. Strabo was a real scholar, painstaking, accurate, critical, who, after examining all possible theories that might account for the stratified rocks and the fossil shells of sea-creatures in them, thus sums up, to quote an old translation, the opinion of the Ancient World concerning them:

"It is not because the lands covered by seas were originally at different altitudes, that the waters have risen, or subsided, or receded from some parts and inundated others. But the reason is, that the same land is sometimes raised up and sometimes depressed, and the sea also is simultaneously raised and depressed, so that it either overflows or returns into its own place again. We must, therefore, ascribe the cause to the ground, either to that ground which is under the sea, or to that which becomes flooded by it, . . .

"It is proper to derive our explanations from things which are obvious, and in some measure of daily occurrence, such as deluges, earthquakes, and volcanic eruptions, and sudden swellings of the land beneath the sea; for the last raise up the sea also; and when the same lands subside again, they occasion the sea to be let down. And it is not merely the small, but the large islands also, and not

merely the islands, but the continents which can be lifted up together with the sea; and both large and small tracts may subside, for habitations and cities, like Bure, Bizona, and many others, have been engulphed by earthquakes."

There speaks the old Roman horse-sense, that looks straight out in front of its nose, sees what is under its eyes, and puts the obvious and common-sense interpretation on what it sees.

This general idea of stratified rocks as old sea-floors, and the fossil shells in them as proof of former invasions of the sea, passed from Greek men of science to Arabian. One of the tenth century—Omar, for example, surnamed "The Wise," not he of the *Rubaiyat* who was of the early twelfth—wrote a book on *The Retreat of the Sea* that has quite the modern sound; and Ibn Sina, better known by his Latin name Avicenna, of the Bagdad Caliphate, the brightest light of Moslem science, only a few years later wrote on mountains quite like the latest schoolbook. Those were the centuries when the learned language of the West was Arabic, and what little of science Christendom knew, filtered out of Bagdad and Cordova, transmitted in no small part by Jews. For all our modern science is in its beginning Greek, and the Arabians and Persians, being nearer geographically to

Greece than to Rome, clung to the Greek scientific tradition centuries after it had faded from the West.

But medieval Christendom did not use either its eyes or its common sense. Instead, it theologized. So Europe took until into the eighteenth Christian century to get back to Strabo and Aristotle. Even now—as we shall see later more at length—pre-Aristotelian opinion obtains widely in the less scholarly portions of these United States, where pudding-stones are held never to have been sea beaches; nor sandstones, deltas or river bars; nor fossil shells, the remains of creatures that died quietly on sea-floor muds.

But if Aristotle had flourished in the modern Athens instead of the ancient one, teaching at Harvard instead of the Lyceum, and if Strabo had mapped for the United States Geological Survey, their general notions concerning the history of the world must still have been just about what they actually were. The rocks of Greece and Egypt prove much of Europe and North Africa to have been once and again beneath the sea. The rocks of North America tell the same tale for the United States.

But the curious thing is that North America, like all the rest of the lands that are old sea-floors,

has not stayed long at a time either under water or above it. On the whole, our American rocks, especially east of the Mississippi, are obvious sea-bottoms, albeit of shallow seas. There are fossil seaweeds in them, and the shells of clams and sea snails, with an occasional coral standing upright in an inland hillside just as it grew on its Paleozoic reef.

But there is also the coal, which is land vegetation, with little air-breathing salamanders and primitive insects fossil in the hollow stumps. There are the fossil tracks of strange dinosaurs that must have walked in shallow water that was often pretty certainly fresh—and these tracks occur in districts as far apart as Massachusetts and Arizona, and in several layers in the same district as if the land had gone up and down many times, as we know it had to, to bury twenty coal-seams one above another. Besides, there are the great deposits of rock salt, where old Dead Seas have dried away.

Moreover, especially in the younger rocks that make up the great plains west of the Mississippi, there are strata that are clearly the floors of ancient fresh-water lakes, for the fossils in them are all fresh-water things. There are also great alluvial fans, such as rivers still form wherever a swift stream comes down out of the mountains laden

WHERE GEOLOGY WAS BORN

Side Wall of the Nile Valley, the Lybian Desert cut through by the river. In the background the horizontal stratified rocks of the old sea-floor. Luxor, Upper Egypt.

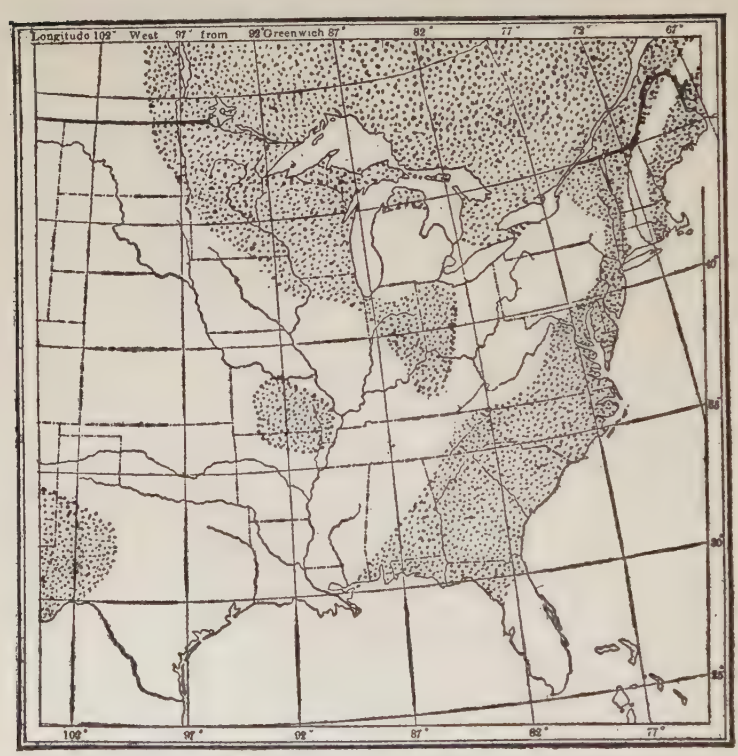
Courtesy of *A. M. Lythgoe, Metropolitan Museum of Art, New York City.*

with silt, and drops its load when its current slackens in the flat country. Clearly, then, the sea-floor does not come up to be dry land and stay up. It warps up locally above the waves. It may even be thrown up into a great mountain range. But by and by, down it goes again, to acquire more beach deposits or be spread over with lake-bottom or sea mud. Later, it will come up in another place. So land is perpetually alternating with the shallow sea, with sea-floor that, as the sailors say, is "in soundings" and less than a hundred fathoms deep.

One must not forget that there are places out on the Grand Bank, two hundred miles from the Newfoundland shore, where men catch codfish off the bottom with a hand-line; and there are plenty of spots in the North Sea, far out of sight of any land, where a big ship can not sink without its masts sticking out. The continents of the world have always been like this. They warp up in one region. They warp down in another. They seesaw up and down, within the time it takes to form a swamp when they are up and to bury it over with a mud-flat when they are down. North America seems never to have had any particular shape. Sometimes it has been larger than it is now. Sometimes it has been cut up into large islands with narrow straits

between, like the East India Islands or a map of Mars.

So much, then, though in vastly less detail, had



After Tarr.

PROBABLE DISTRIBUTION OF LAND (STIPPLED) AND WATER (BLANK) DURING MOST OF THE COAL PERIOD

Aristotle and Strabo made out for their districts before the Christian Era dawned. So much may the traveler still make out almost anywhere in the

interior of North America, seeing everywhere in the hillsides signs of an ancient, shallow Gulf of Mexico, that sometimes extended to the Great Lakes, and sometimes went clear through to the Arctic beyond Alaska, and sometimes shrunk away to leave fresh-water lakes and dry land where the sea had been, only to come back once more to put down another layer over the wheat country or the high plains. So the land goes, up and down, sea to shore, "with no trace of a beginning and no prospect of an end."

But if fossil sea-shells in the mountainside really do prove that the sea has aforetime been where land now is, then something else follows that is still harder to believe.

It takes time for the sea waves to knock angular blocks off the headlands, round them off into beach pebbles, and grind them up into sand. It takes time for the sea to creep in over the land, or for the land to rise up out of the sea. The great Tigris-Euphrates delta has grown only a hundred miles in the course of history. Omar the Wise had to check back on ancient Persian and Indian maps of two thousand years before his time to prove that his side of Asia is larger than it was. Any one of us has only to watch delta or mud-flat grow, to see how minute is the annual increment, and how vast

therefore must be the time needed to build the half-mile of slate and limestone that we see, layer upon layer, heaped up on a mountain's flank. The earth is altering very slowly as human lifetimes go; and any fool can reckon that unless it has altered in the past some millions of times faster than it is changing now, then the earth must be enormously old.

The open-minded Greeks, having no theology to bother them, took the inevitable conclusion. The Romans followed the Greeks, as in most matters not too obviously practical. The Arabians in the great days of Islam followed both—albeit, with some misgivings. Luckily, Mohammed—"may Allah rejoice his soul"—was not interested in natural history, was chary of opinions about matters he did not understand, and so did not commit his followers to a vast deal of nonsense concerning matters of science.

Geologic time, therefore, for much of the ancient world, took on almost modern dimensions. There was, in particular, the doctrine of Great Years, the period of the long-drawn cosmic cycle through which the universe passes, only to return again to a good deal the same state as at the beginning.

The idea was widely popular in antiquity, the Stoics in particular developing it very far, even to

successive burnings and liquefactions and subsequent re-creations of the universe. This general notion passed over into Judaism, assimilated its Great Winter to Noah's Flood, and gives us our Christian doctrine of the final destruction of the earth by fire.

There were, naturally, many attempts to fix the length of this Annus Magnus—for the most part, however, by astronomical data rather than geological.

Aristotle, who seems to have connected the seasons of the Great Year with retreats and advances of the sea, suggested that its length is the least common multiple of the periods of the seven planets, so that the Great Year comes to an end when all seven get back to the same configuration that they had at the start. This, of course, associates the Great Year with the astrology so widely current in the ancient world. Cicero calculated its length as 12,954 ordinary years.

On the other hand, there is the precession of the equinoxes, which Hipparchus, at the Alexandrian Observatory, using old Babylonian observations, discovered shortly before the beginning of the Christian Era; and Ptolemy, also of the Observatory staff, in the second century A. D., calculated to complete its cycle in thirty-six thousand years,

but which really does take about twenty-five thousand eight hundred. So thirty-six thousand ordinary years also figure widely as one Annus Magnus.

Other figures are reported, even as high as seven hundred and sixty thousand terrestrial years—but numbers are prone to be uncertain in ancient texts. In any case, the Great Year was very long. And since the Great Year itself is only a time division, time itself must have been thought of as at least into the million years. Aristotle held the universe to be eternal; and Averroes, the great Mohammedan scholar of the Middle Ages, who was Aristotle's interpreter to Christian Europe, followed his master also in this. But Christian theology, tied up to the Genesis account of a creation in six days, somewhere between 4000 and 6000 B. C., according as one follows one or another of variant Biblical manuscripts, had no place for any Great Year, though Christian scholars were not unfamiliar with the concept after Greek and Arabian ideas began to trickle into western Europe during the Crusades.

Here then was an obvious dilemma. Christian Europe followed its sacred text, taken as read. The Biblical account takes over the Babylonian story. The Babylonians, having no geology, had

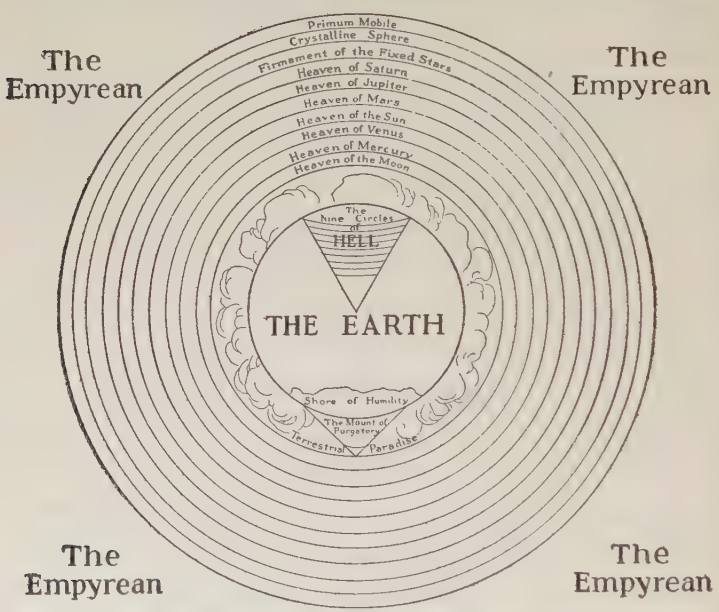
no idea of geologic time. So the world, for Christian theology, is only a few thousand years old. Therefore it follows, logic being logic, that the stratified rocks of earth are not old sea-floors, nor the fossils in them ever the shells and teeth and skeletons of real sea-creatures that lived and died in the mud, and were slowly covered over as more mud sifted down upon them grain by grain. Christian Europe, up to the beginning of the sixteenth century, refused consistently to believe its eyes.

The history of European learning, then, for the last three thousand years, and most especially the history of geologic science, is really the history of the long-drawn conflict between Greece and Babylon.

Babylon and its colonies, earlier than 1000 B. C., had reached a notion of the cosmos as the creation of one or other of the gods, not so very old, centered on a flat and immovable earth. And because Babylon the Great took little Israel captive, Babylonian cosmology colored decidedly the language of important portions of the Bible, and passed thence to Islam and Christianity. So three great religions reflect in no small measure that set of geological ideas.

But Greece and its colonies, from 500 B. C. onward, inclined to a very old universe, more or less

self-existent and so not needing any creator, with a round earth that spins on its axis and may quite possibly revolve around the sun. That notion also invaded both Islam and Christendom, so that, for



From the author's *Understanding of Religion,* Houghton Mifflin. After S. Humphrey Gurteen's *The Epic of the Fall of Man,* Putnam's.

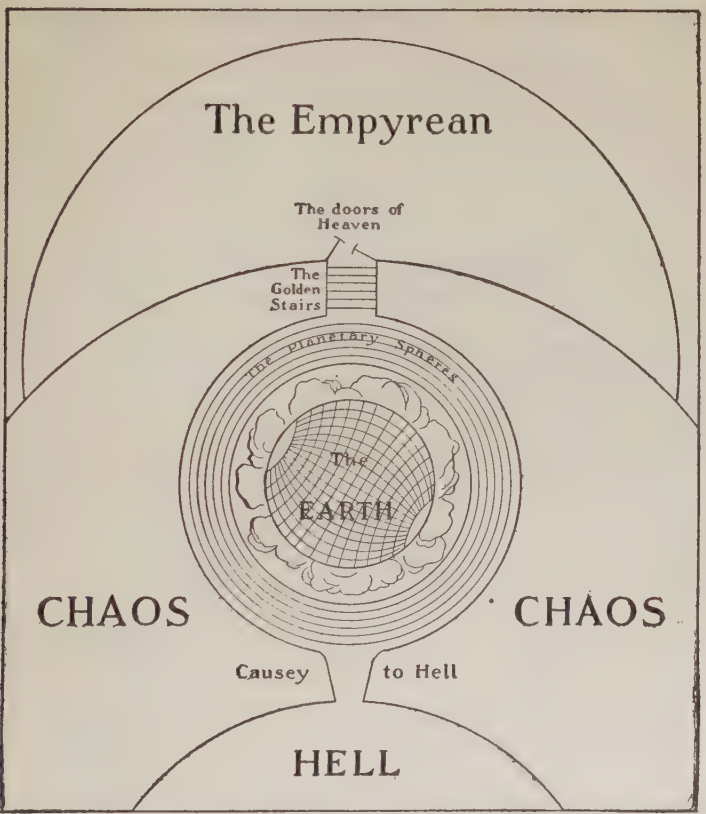
DANTE'S UNIVERSE OF THE THIRTEENTH CENTURY

The earth, fixed at the center of the cosmos, is surrounded by the planetary heavens. The scheme is purely Ptolemaic and there is no hint of any flat earth.

two millennia, Greece and Babylon, alternately or in conflict, have ruled Europe.

Greece kept the saddle for the first five hundred years of the Christian Era, and Europe had a

science essentially like our own. Then Babylon came back, and for the next five hundred years men once more believed in a flat earth and all the



From the author's *Understanding of Religion,* Houghton Mifflin. Greatly modified after S. Humphrey's Gurteen's *The Epic of the Fall of Man,* Putnam's.

MILTON'S UNIVERSE OF THE SEVENTEENTH CENTURY

The scheme is partly Ptolemaic; but there is a return toward the notion of a flat earth in a three-storied universe; since, in spite of the planetary heavens, Heaven itself is above the earth and Hell below.

rest that goes with it. After that, very slowly, Babylon fell. By 1300 A. D. Dante knows that the earth is round. But Milton, writing in 1667, is not sure that it moves. Even in this year of grace, there is at least one fair-sized city in these United States where the pupils in the public schools are taught that the earth is flat, and there are plenty more where "the globular hypothesis," though permissible, has to be handled tactfully.

With such travail has our own European world come pretty much back to what it knew before the ancient Roman Empire started going generally to the dogs.

CHAPTER IV

THE FLOOD THEORY OF FOSSILS

The Revival of Learning—which, for convenience, we may date by the invention of printing, a half-century before the discovery of America—along with books, the mariner's compass, gunpowder, standing armies, and other conveniences of civilized life, had also the highly important effect of turning the European mind away from Heaven and the Church to natural science and the things of this world. Men still theologized as to creation in the beginning, and how human beings walking feet upward on the other side of the earth could manage to hear Gabriel's trumpet on the resurrection morn. But they also circumnavigated Africa, brought about the Reformation, sent their bright boys to college to learn Greek and Latin, and what is for the moment more important for us, they began once more to look around them after the manner of the Ancient World, to make out at first hand what the hills and the rocks are actually like.

Thus the great Italian painter, Leonardo da

Vinci, born in 1452, who was also an equally great engineer, had occasion in his youth to plan and put through certain navigable canals in the northern districts of the peninsula, through stratified and fossiliferous rocks that are rather late in geologic age. There in Leonardo's rubble were leaves, seaweeds, marine crabs, besides the usual snails and clams, all a good deal like present-day creatures, and none much altered from the same things that any Italian might see on a modern shore. Italy is geologically young; and the early Italian geologists of the Renaissance found themselves quite unable to draw any line between the living creatures of the tidal pools and the fossil creatures in the cliffs above. There were also the loose beach gravels—and through indurated gravels precisely like them Leonardo drove his canals. There were dead shells on the shore, filled with sand or mud—and there were sandstones and slates with shells in them, that Leonardo had to quarry out for his ditches.

So Leonardo used his common sense. Some of his countrymen did likewise; and the old Greek notion of stratified rocks as old sea-floors and geologic time as enormously long, reviving first in Italy, gradually spread itself over the western world.

Most learned men, however, in the sixteenth and seventeenth centuries in Europe, were not naturalists, but theologians. They had, therefore, a dogma to maintain—the recent creation of the earth out of nothing, a creation very much too recent to give room for even a small fraction of geologic time. The earth, reasoned the clergy, no matter what it looks like, can not possibly be a million years old. Therefore, they set themselves to explaining away the stratified rocks.

Fossils are, of course, the key to the matter. But how, argued no small part of the learned world even into the eighteenth century, do we know that fossils really are the remains of any creatures once alive? God creates: he can create inside the rocks as well as out. We are, indeed, told in Holy Writ that "the earth brought forth abundantly the moving creature that hath life." But we are nowhere informed that all the living creatures that the earth produced ever won clear of the enveloping soil and reached the upper air. Fossils are aborted creations, monsters, things that never quite came to life, models on which the Creator worked out his final plans. Science displays a pitiable lack of imagination when it supposes that because petrifactions in the rocks look a good deal like shells and leaves and teeth and bones, they really are such.

This general notion of fossils as part of the primary creations "in the beginning" must have lingered late among the unlearned. In fact, it probably lingers still, if one knew where to look for it. William Denton, for example, in his *Our Planet, Its Past and Future* of 1868, relates: "I saw a Cornishman digging for lead in Wisconsin, and asked him where he supposed the shells came from that abound in the limestone there. 'Why,' said he, 'I suppose the Lord made them when he made the rocks.'" So Denton spends his next three pages arguing down created fossils.

Besides—to quote once more the theologians of the early modern period up to, let us say, about 1750—we all know that the air and the water—and even the solid rocks as well—contain innumerable living germs, too small to be seen, which only need to fall or float to the right environment, to start up growing and become the familiar animals and plants that we see. This is the old "dissemination theory" that supposed that successive generations of living things are not really produced by their apparent forebears, but come as created germs in the air, fall directly upon plant blossoms, make their way into animal bodies in food or drink, and become seed or young quite independently of any quality of their bearing mothers. So, naturally,

such germs might well fall into a crevice in a ledge or be washed into a cave, there to develop far enough to take on the form of a living thing, but without ever really coming to life. Probably, too, since fossils of the same sort are apt to occur together in considerable numbers, these lifelike but never living forms do in some fashion breed and multiply inside the rocks.

In short, there is no end to the ingenious but not very convincing theories which scholars and theologians, sitting in their studies, excogitated from the depths of their intellects to confute the simple-minded people who looked at the rocks out-of-doors and compared one fossil with another and both with their living counterparts. Even as late as the end of the seventeenth century, John Ray, who was the leading British naturalist of his time, a really great scientist and one uncommonly free from non-scientific prejudice, after a long discussion of fossils from many points of view, inclines on the whole to the opinion that the shells and bones and teeth of British strata have never been parts of any living things. So much, only two centuries ago, were men afraid to use their eyes and their common sense.

But after the eighteenth century came in, the preferred method of explaining away the stratified

rocks and abolishing geologic time proved to be by way of Noah's Flood. And because that remains the favorite method still, the rise of it, its history, and its downfall in the learned world along through the middle years of the eighteenth century, has for us even now much more than academic interest. The old notion of all the stratified rocks as the deposit from the Great Deluge, which seemed to have been thoroughly threshed out and finally disposed of before the American Revolution, has in these last days been again revived, is set forth as the latest science in portions of the denominational press, is taught for good geology in certain denominational schools, and is really one of the foundation stones of the vast edifice of present-day pseudoscience, which most of us glimpse only as the current attack on evolution.

The general idea is old, prescientific in fact, in Christian Europe, for it goes at least back to the days when Christian theology was struggling with the dying paganism, not the reborn. In brief, there seems never to have been a time, from the period of the Church Fathers down to the present year of grace, when some eminent divine—with occasionally some layman—surveying the earth with more breadth of view than detailed attention, has not seen in the stratified rocks the wash of Noah's

Flood, and in their fossils the remains of creatures that perished in it.

The palmy days of the doctrine were early in the eighteenth century; but it never quite lapsed out of all knowledge between the beginning of the nineteenth and its latest revival in non-scientific circles at the beginning of the twentieth.

Naturally enough, a doctrine of this sort, evolved by speculative theologians out of their own insides, not an induction from any objective evidence, was bound to take on a great variety of forms. In fact, from about Newton's time, well past Cuvier's day, that is from the beginning of the seventeenth century well into the nineteenth, an ecclesiastic with ambitions hardly felt himself worthy of promotion in his church unless he had written at least one volume to set forth some new theory of Noah's Deluge, that did not agree with any other man's, and commonly agreed still less with any known evidence There were Treatises on the Deluge, Sacred Theories of the Earth, a *Moses' Principia,* an *Origines Sacræ,* a *Comparative Estimate of the Mineral and Mosaic Geologies,* and even as late as 1823, the *Reliquiæ Diluvianæ* of William Buckland, who besides being a Doctor of Divinity and dean of a cathedral, was also a Fellow of the Royal Society and one of the first half-dozen British geologists of his day.

It is easy enough to laugh at these ancient worthies—still easier is it to ridicule their successors of to-day—who accept the Biblical account of Noah's great flood and try to find some sign of it in the present-day earth. But what is one to do who believes the Bible at all? That problem of adjusting Greek science and Hebrew theology faced Philo Judæus before there was any Christian Church. It faced the Platonizing Fathers in the Church's early days. It faced the Schoolmen down through the Middle Ages. It faced the seventeenth and eighteenth centuries, and the first half of the nineteenth. It still faces half the United States; for a Fundamentalist is simply one who, unlike the rest of us, has not yet given the problem up. Islam encountered the same difficulty with its Koran, and was beaten by it. That is one reason why Moslem science, which once led the world, amounts to nothing now

So the history of geology for half its course in Christendom is the history of successive flood theories. They linger still over half the area of the United States in substantially the same form in which they were set forth in 1695, in Dr. John Woodward's *Essay toward a Natural History of the Earth and Terrestrial Bodies, especially minerals; as also of the Sea, Rivers, and Springs, with*

an account of the Universal Deluge, and of the Effects that it had upon the Earth.

John Woodward, M. D., was an important person in his day, Professor of Physic at Cambridge, authority on smallpox, the bile, and the Bible, founder of a professorship in geology at his University, and a collector of minerals and fossils whose collection is on exhibit still. John Gay, dramatist and poet, put him into one of his farces as "Dr. Fossile, the man who has the Raree-show of Oyster-shells and Pubble-stones." Another poet wrote a burlesque epic on this flood theory. A brother physician who held different views from Woodward concerning the functions and diseases of the bile ridiculed him in *The Life and Adventures of Don Bilioso de l'Estomac;* while still another practitioner forced him into a duel on a technical point in medicine, and Woodward's foot slipping, it might have gone hard with the geologist-physician, if the bystanders had not interfered. But according to Woodward's account, "Had he been to have given me any of his physic, I would, rather than take it, have asked my life of him; but for his sword it was very harmless."

Now, this father of all flood theories lies in Westminster Abbey, with a Latin inscription over his remains, close beside Sir Isaac Newton who was

his friend in life; while the Woodwardian Professorship at Cambridge still remains one of the considerable prizes of British science. Such was the man who, for the English-speaking world, put forth the first really scientific theory of fossils and the stratified rocks that makes them all, from top to bottom, relics of Noah's Flood.

According to Woodward's old theory, the earth itself is hollow and full of water, a sort of child's rubber ball that is all ready to squirt, with only a thin shell around the liquid. The interior is the Great Deep of Scripture; and when "the fountains of the great deep were broken up" the interior ocean flooded all the lands.

But Woodward, unlike his present-day disciples, was not only a speculator but a naturalist, who in order to inform himself of the present condition of the earth had traveled over the greater part of England, inquiring "for intelligence of all Places where the Entrails of the Earth were laid open, either by Nature (if I may so say), or by Art, and humane Industry. And wheresoever I had notice of any considerable natural Spelunca or Grotto, any digging for Wells of Water, or for Earths, Clays, Marle, Sand, Gravel, Chalk, Cole, Stone, Marble, Ores of Metals, or the like, I forthwith had recourse thereunto; and taking a just account

of every observable Circumstance of the Earth, Stone, Metal, or other Matter, from the Surface quite down to the bottom of the pit, I entered it carefully into a Journal, which I carry'd along with me for that purpose."

So Woodward, besides being a diligent student of the Bible and a leading physician of his time, was also one of the earliest of British working geologists. But he never was able to frame any explanation that satisfied his critical contemporaries as to why, given a flood violent enough to wash up all the stratified rocks of earth at once, it should ever have deposited them in any sort of regular strata. All like theories since his day and up to the present have wrecked themselves on the same bar.

After Woodward's time, then, scientific as distinguished from theological speculation concerning the earth's past, tended strongly toward accounting for the actual rock strata visible in the hillsides by far more than a single great deluge. No one flood, the eighteenth century reasoned, can have dropped down, within a few weeks, out of diluvial mud, layers of pudding-stone and sandstone and slate and limestone and chalk and coal, various in color, paper-thin or thick as a house is high, each with its proper fossils, fresh-water and salt-water forms

never in the same layer, modern fishes never in the same stratum with trilobites, flying reptiles never mixed with modern birds, and above all, no human remains, either implements or skeletons, ever associated with any kind of creature except such as are just about like those of the present day. One must, therefore, either suppose that there was a series of great deluges, of which Noah's was only the last and possibly not the most important; or else one must suppose that the Great Deluge of Noah somehow quite missed its object and no sinful antediluvians were actually drowned in it. Human remains, either bones or artifacts, are *not* found in the stratified rocks. That was clear by the end of the eighteenth century.

Noah's great deluge, then, for the early nineteenth century accounted for only the so-called "diluvium," the superficial, unconsolidated stuff which almost universally in northern Europe and northern North America, overlies the proper, hard stratified rocks. We know now that most of this is glacial drift, but before the middle of the last century few persons took stock in any Ice Age. But in less than a hundred years, the old Woodwardian notion that the Biblical Deluge accounts for all the stratified rocks, had been whittled away to the doctrine that it accounts for none of them.

Then came the problem of the "diluvium" and the cave deposits. Were these really, as Buckland and others maintained, the sure proof of the Great Flood and the vindication of Holy Writ against "science falsely so-called?"

Owen, among others, who was born in 1804 and after Cuvier's death took Cuvier's place as the leading anatomist of the day—to take but one example out of many—attacked this last problem most ingeniously.

It was argued in scientific circles in Owen's day—as it is argued in certain theological circles now—that the considerable number of elephant skeletons and teeth in regions far to the north of any present-day range of similar creatures, indicates some universal deluge that floated these remains to the spots where they are now found. Therefore, must the drift, which so generally in northern latitudes overlies the hard rocks, be witness to Noah's Flood.

Owen to this makes answer that the great Irish elk, now extinct, also occurs widely along with other mammals whose remains testify to Noah's Flood. But the Irish elk, like all deer, sheds its horns annually, a male deer on the average growing something like eight pairs of antlers in a lifetime. If, then, our fossil *Megaceros hibernicus* is

now found where it originally lived, each creature buried over about where it perished, there should be—since the female has no antlers—about four times as many pairs of antlers as of skulls, or of pairs of hoofs, or of particular teeth. But if, on the other hand, the diluvialists are correct, and a wild flood of waters, overwhelming all the land, has swept away the drowned carcasses and floated them to the bone-beds where we find them now, then the number of antlers should just about correspond to the number of other hard parts.

So Owen checked up carefully the relative numbers of horns and hoofs and teeth and skulls. It turns out that antlers of the great Irish elk are rather more than four times as numerous as the other remains!

Another curious fact came to light about these elk bones and other remains of extinct creatures found along with them: many of these bones—nearly all in fact of those supposed to have been washed by the Great Flood into caves—are scratched as if by the teeth of some powerful dog-like creature.

So Buckland, who in the 1820's, was the outstanding supporter among men of science of the Deluge Theory of cave deposits and the drift, took to feeding beef bones to the hyenas in the London

zoo. Buckland found that the London hyenas marked their beef bones precisely like the markings on his cave deposits. Buckland, moreover, found sometimes as many as a hundred fossil hyenas in a single cave, their bones also tooth-marked as hyenas themselves apparently gnawed their fellow carnivora. Hyenas nowadays drag home their prey to their dens to eat. Buckland had to decide whether, taking all the facts together, the cave deposits on which he was the first British authority were best accounted for by his earlier hypothesis of inwash by Noah's Flood, or by the alternative hypothesis of hungry carnivora.

Therefore, in the summer of 1836 Buckland, already President of the Royal Society, but not yet Dean of Westminster, went over to Switzerland to consult his good friend Louis Agassiz; and the two threshed out the problem of glaciers against Noah's Deluge up and down the high valleys of the Alps. Then in 1840, Agassiz came over to see Buckland, and the two geologists tramped and argued through the Highland glens of Bonnie Scotland. As a result, in the fall of 1840, Reverend William Buckland, D. D. and F. R. S., Copley Medalist, Professor of Geology at Oxford, author of a Bridgewater Treatise, stood up in a meeting of the Geological Society of London and took back

everything he had ever said concerning any sign of Noah's Deluge in Great Britain.

That is the sort of man William Buckland was. Because he was that sort of a man and everybody knew it, from that moment Noah's Deluge as geologic agent disappears for ever from scientific ken.

In brief, then, the notion that fossil animals and plants are the remains in the rocks of creatures destroyed in the Great Flood, and that other and older notion that such fossils have never been alive at all, did manage, between them, to hold back the progress of geologic science for just about three centuries.

Neither opinion ever rested on evidence from fact. Both were essentially theological speculations, motivated by a desire—legitimate to be sure—to make science and theology agree. Why one of the two notions still survives among the speculative and unscientific and in districts where voters still think the earth is flat, while the other seems to have perished utterly, is a point which various persons have remarked upon, and nobody has been able to settle.

CHAPTER V

THE ONION-COAT EARTH

By the close of the eighteenth century, then, the learned world had pretty well made up its mind that the common rocks which commonplace people saw everywhere about them and used to build their walls, are no part of any originally created earth; neither are they any deposits from the mud stirred up by any universal flood. If there ever was any universal flood—a point on which, even before the beginning of the eighteenth century, an occasional theologian had begun to have misgivings—even then, it accounted only for the "diluvium," as Buckland afterward called it, that is to say, the unconsolidated soils and gravels which mantle the hard rocks, and yet are obviously not quite as new as the dunes and meadows. So the layered rocks, miles thick, apparently all water-deposited, were to be accounted for without the help of Noah's Flood.

With this, for the late eighteenth century, went still another problem closely related to it. There in the hillsides are the stratified rocks, shales and marbles and chalks and pudding-stones, their lay-

ers piled one above another "like slices of bread and butter." One knows how thick these layers are because one can see their broken edges. The problem is: How far do they extend horizontally?

Clear round the earth, most of them, said Abraham Gottlob Werner, Professor of Mineralogy at the University of Freiberg from 1775 on, and altogether the most illustrious and the most influential student and teacher of earth-science of his day. That purely speculative opinion had also to be lived down before the new-old science of geology could clear itself from cosmological speculation of all sorts, and come down to its proper business of interpreting facts. Natural science, in the late seventeen hundreds, was still the handmaid of theology; and it still employed the tools of its mistress.

Werner had the typical eighteenth-century mind, able and logical and clear, the sort of mind that will "hold these truths to be self-evident," as the *Declaration* puts it, and perfectly content with that, will never notice the enormous complexity and illogic of the actual world of men and things, nor how very rarely either nature or man ever does anything in the least as they self-evidently ought. Werner, in short, treated the stratified rocks just about as Rousseau treated Human Nature or Adam Smith the Economic Man.

Werner did not look any eighteenth-century part—unless, perhaps the Industrious Apprentice. His pictures show an undersized, shy creature with a pug nose. But he could speak with the tongues of men and of angels; with the result, as Cuvier said in pronouncing his eulogy—as Cuvier had occasion to do for many distinguished persons and did uncommonly well—"In a few years, a small school of mines, before unheard of in Europe, was elevated to the rank of a great university; and men already distinguished in science studied the German language, and came from the most distant countries to hear the great oracle of geology."

Werner had behind him some dozen generations of miners of the Erzgebirge, and his proper task was to train mining engineers. But he managed incidentally to talk on all the economic and medicinal uses of minerals; the effect of sand deserts and granitic mountains and fertile plains on manners and wealth and language and intelligence; on styles of architecture as affected by local building stone; on the relation of physical geography to military systems. As the rocks determine the soils, and the soils determine the crops, and the crops determine the food supply, and the food supply determines the inhabitants, and men make history, so Werner at Freiberg, beginning with the year of Concord

and Bunker Hill, founded a university education on the metalliferous veins of Saxony. That timid little man was perhaps the greatest teacher that has ever faced a laboratory class.

The greatest, perhaps, but certainly among the most mistaken! Geologists ought above all things to rove the world, noting

"The different ways that different things are done"

by an infinitely various Nature,

"An' go observin' matters till they die."

Werner did not do this. He sat tight in Freiberg, letting the world make a pathway to his door, while he held these truths to be self-evident, that whatever is true for Saxony is true also for all the rest of earth, and there is no use wearing out one's shoes.

Werner's geology was of the wettest sort. All strata, he maintained, are precipitates out of a universal ocean—even the granites and the old lavas. In fact, he taught that there were no volcanoes in the earth's wild youth, and only late in life did the world take to having eruptions and lava flows.

Of some fifty-odd different sorts of rocks—for

Werner, we must not forget, taught practical mining—the granites in particular, with many of the gneisses and schists, were, as he said, "primitive." They were, in his system, the first precipitate out of an all-encircling ocean before there were any living things on earth. This opinion, that the granites are especially old, is still widely held in non-scientific circles.

There were five main eras in all—four in some variants of the system—with the first organic remains coming in with the second, just above the granites, and with the coal in the third. But with the third great era, the ocean no longer covers all the earth, so that in this and the two succeeding eras, the formations are not absolutely universal. But the point of Werner's system is that a particular sort of rock marks always a particular point of time. That particular formation is laid down everywhere at once and once for all.

In this way, Werner met the great difficulty of all Noachian flood theories, the sorting out of animal and plant remains, by supposing a gradual creation of the animals and plants. The earliest creatures were brought forth, and then buried. Then came a new set created after them; and later, more and more. Thus any succession of living things that actually turns up, one sort above an-

other in the known rocks, is accounted for in advance. Werner's school, then, made the first real attempt to explain the succession of animal and plant species in geologic time.

These late eighteenth-century opinions were really a great deal more complex, as well as a great deal more reasonable, than they are often represented as being. Thus to quote Werner's pupil, D'Aubuisson of the French Board of Mines—for Werner himself, like many another great talker, wrote almost nothing—his *Account of the Basalts of Saxony* of 1803, done into English by a Secretary to the Wernerian Natural History Society and printed in 1814:

"Let us carry back our ideas to the time when the present crust of the globe was formed. The nucleus must of course have previously existed. It was surrounded, we may suppose, with an universal ocean, holding various matters in solution: the precipitates or sediments were deposited one above another: each of them formed a bed or a stratum, which, in moulding itself over the preceding, naturally followed the bendings, heights and hollows which occurred, maintaining throughout nearly a parallel thickness. [That is, apparently, folded rocks were laid down as folds; not flat and afterward bent, as present opinion

is.] . . . and as all the layers must then have surrounded the whole globe, they could have no upper edges or *outgoings.*

"Let it next be supposed, that the waters had become lower in their level, so that certain elevated points or mountains remained uncovered; it is evident, that no subsequent precipitates or sediments could form beds surrounding the whole globe: their upper edges would necessarily be wrapped around the elevated points alluded to, which would afterwards appear as if they had pierced those beds, and risen above them. [This just reverses current opinion.] In proportion as the waters became lower in level, the *outgoings* or upper edges of the beds successively formed, would necessarily be lower. . . . If . . . the waters should again rise, and the older and denuded part of the mountain should be covered with a new formation of beds, . . . Thus, whenever we find a formation of mineral beds, . . . we may safely conclude, that such rocks have undergone a certain degree of wasting and disintegration before the new formation took place; or, what appears generally to have been the case, that a long interval elapsed between the periods of the two formations."

And then fifty pages farther on:

"From these observations, Professor Werner

concludes, that the globe of the Earth is of remote antiquity; that its surface was inhabited by animals, and covered with vast forests, when it underwent a great revolution, perhaps the last of several which it has experienced; that this revolution occasioned the disintegration of many of the rocky masses already existing,—the total destruction of the forests,—and was followed or accompanied by a mighty inundation, which rose to a height, equal perhaps to that of the highest mountains; that this immense and necessarily raging sea produced accumulations of gravel and sand, over which, when it had somewhat abated of its agitation, were deposited the earthy, clayey, and bituminous particles with which it was charged: that as the water became more and more tranquil and pure, the precipitates had become less earthy, and the union between their particles more intimate; wacke, basalt, greenstone, and porphyry-slate, being successively produced, as it approached to that state of calm and purity, favourable to crystallization."

In other words, we have here what is essentially a multiple-flood theory of the stratified rocks, though the ghost of Archbishop Usher no longer haunts the hills. The dry land has stood long above the ocean, and its rocks have weathered into soil. Then the flood rises and covers everything but the

high mountains, washes away all the softer stuff, and drops this down in new layers. The point of all theories of this type is that the stratified rocks are deposited by fits and starts, very rapidly while the deposition goes on, but with long intervals of quiet between our earth's several spells of getting something done.

This is, in short, a catastrophic geology in contrast to the uniformitarianism that began to supplant it just about a century ago. Cuvier, early in the century, was the great prophet of catastrophism, and Agassiz, about the middle, the last of its apostles, up to its current, non-scientific revival. Of necessity, a catastrophic geology presupposes an "onion-coat" earth; for the catastrophes must be nearly or quite world-wide, and each therefore has to lay down a nearly universal formation. Catastrophism, therefore, gradually faded out as the progress of geologic exploration proved that the globe does *not* have "onion coats." First there was one Great Deluge. Then there were several, Noah's being the last. Then there were many—De Beaumont was finally driven to admitting seven for the Pyrenees Mountains alone; Agassiz allowed fifty to a hundred, and all the "catastrophes" were not floods. In the end, the floods came every spring and even the catastrophes became "uniform."

Even so, this general Wernerian conception of a limited number of more or less periodic flood-like "catastrophes, of nearly or quite universal deposits, of eras and periods necessarily world-wide, of fixed relation between the looks of a rock and its age"—in short, the whole notion of an "onion-coat" earth—lingered surprisingly in minds as a half-unconscious, fixed idea. Werner was, indeed, another Agassiz—a marvelous teacher much given to being wrong. But Werner taught his pupils to see with his eyes, unlike Agassiz who taught his to use their own. The latter's pupils all promptly abandoned their master's views. But Werner's pupils so clung to his opinions in the face of all evidence that, of well-known men, Von Humboldt only really broke away. So Werner's theories, clear and interesting and falsely simple, had so vast a popular following that even so late as 1862 Huxley thought it wise to utter warning even to a scientific public against lingering traces of Werner's views.

But the scientific world—barring most of Werner's old pupils except three or four of the most eminent—promptly made way with Werner's doctrines. Werner thought that traps and basalts—such as, for example, form the Hudson River Palisades above New York—are water precipitates. But the French and Italian geologists,

Palisades of the Hudson River above New York

Courtesy of the *Cornell University Physiography Laboratory*

in a district where there are old lava flows and old volcanic peaks and young volcanoes that have lately erupted and still newer ones that start erupting unexpectedly, had no difficulty in proving that all the traps and basalts and similar rocks are essentially lavas, and not in the least precipitates out of primitive oceans.

Werner's doctrine, in fact, encountered a good deal the same difficulty from the basalts and lavas that the older Flood Theory did at about the same time from the same source. Neither Werner's universal ocean nor Noah's universal flood can well be imagined to put down sheets of rock, evidently once liquid and now frozen, over and over again, with evident old sea-floors above and below. So the "onion-coat" earth and the Biblical flood waters faded from scientific view at a good deal the same period.

Granites, either as the original crust over a molten globe or as the primitive deposit older than all living things, took their great facer at the hands of an Edinburgh Scot, one James Hutton, who had *not* been Werner's pupil.

Hutton had argued on theoretic grounds that the granites are only coarse-grained lavas that have cooled slowly, and may therefore be of any age. The difficulty was to prove the point. Finally, in

1785, after some hunting, Hutton discovered in Glen Tilt, in the Grampian Hills, just north of Edinburgh, a mass of red granite that should by all current theory be part of the earth's first rocks, and over it limestone and black schist that should have been formed next later, that is to say in Werner's "Transition Period," as in those days they called the Paleozoic Age.

Alas for the oft-enacted tragedy of natural science—the beautiful theory confronted by the beastly fact! The granite mass sent out dikes into the strata over it. Therefore, it must have come in melted. Moreover, before the granite had frozen, it had baked the rock in contact with it. Therefore, on two counts, was the granite proved to be younger, not older than the schist and limestone; and Werner's whole system came tumbling down around his disciples' ears. Hutton, it is related, cut such un-Scot-like capers in front of that strip of red granite that his gillie thought he had discovered gold.

What Hutton had done—though he did not know it to his death—was to end some three thousand years of speculative cosmology and usher in the present era of a purely scientific geology. With about his date, men who wanted to understand the earth, tramped over it. The Geological

Society of London began in 1807. The science of geology at last stood on its own feet.

Those were, indeed, the brave days of earth-science—from, let us say, a decade or two before 1795 when Cuvier arrived in Paris, to a decade or two after the first printing of Sir Charles Lyell's *Principles of Geology* in 1830.

The great science of geology is technical and hard and highly specialized if one is to break new ground—though facile, and delightful enough for any free-and-easy duffer still—and all the easy guessing has been done. There are thrills even now—dinosaur eggs, for example, and ancient human skulls. But those dinosaur eggs took a camel train and a score or two of experts, besides—along with other things—a quarter-million dollars. The days are gone for ever when Werner could begin an epoch in his science within a day's walk of his lecture-room and Hutton could end it fifty miles from his own door.

On the other hand, before the heroic age began, geologic science was too easy to be interesting. One decided what Nature should have done, and let it go at that. The method is not obsolete—but it is no longer science.

With Werner's time, came the era of exploration, little part as Werner himself had in it. Von

Humboldt, who was a rich man, just at the turn of the century, ran over to Central and South America to test one of his hypotheses concerning mountain-building. Von Buch, also both of the nobility and a pupil of Werner, walked the highlands of Europe, from Italy and Albania to Lapland and Scandinavia with only silk stockings and a clean shirt, no doubt ruffled, for luggage. William Maclure, "the Father of American Geology," crossed the Allegheny Mountains fifty times on foot. De Saussure, Professor at Geneva, in 1787, was the first of mankind to scale Mont Blanc.

One could still play the old speculative game in those great days—Werner, confronted by inconvenient signs of fusion in a basalt that should have been a precipitate from water, had only to imagine a neighboring bed of coal set on fire and burning without draft, for Lavoisier's studies of combustion had been prematurely cut off along with Lavoisier's head by Revolutionists who held their own special lot of truths to be self-evident.

But even so, observers were at work, methods were fresh and sound, facts were piling up, and the most ingenious of theories might tumble to pieces over night. These are the conditions that make science interesting. One sees them in geography after Columbus came home; in biology after Darwin; in physics and astronomy now.

These geologists of the late eighteenth century and early nineteenth were about the last scientific persons openly to flout the law of parsimony: for one does not, in this, count the psychologists, who for the most part have been only semi-scientific.

This law of parsimony is a basic principle of science—and, indeed of all thinking—an old principle, too, that goes back to the Middle Ages. "Occam's razor" is its usual form, after William of Occam, *Doctor Singularis et Invincibilis,* who died in 1347. *"Entia,"* it runs, *"non sunt multiplicanda praeter necessitatem."*

This simply means *in lingua vernacula* that one really can not just go ahead and imagine all sorts of causes and all sorts of things—floods and special creations and encounters with comets and excessive carbon dioxide in the atmosphere—just as he happens to like, regardless of whether any human being has ever detected anything of the sort in the actual world. Science, in fact, begins only as men confine themselves to accounting for the unknown by the known—not the unknown by something about which they know still less.

But the catastrophic and onion-coat geology, in either its eighteenth-century or its twentieth-century forms, has no place in its field-kit for Occam's razor. Does it need a universal flood? It imagines

one, mountain high. Does it need vast billows to sweep over the flooded land? It imagines tidal and earthquake waves with whatever detail and quality the theory suggests.

Thus once more Werner's disciple of 1803:

". . . I have myself seen basalt, on the summit of the Giant Mountains, at the height of more than 4,000 feet above the level of the sea: it is evident, therefore, that the solution which produced basalt, must have covered nearly the whole globe, or must have been *universal*: but it does not follow, that the precipitate or deposition, must also have been *universal;* for,

"1. The solution may very well be supposed not to have contained, at the same time, and throughout its whole extent, the same constituent parts, or not to have contained them everywhere in the same proportions. . . .

"2. Local causes, such as a subtraction of caloric, or the presence of certain precipitants, may have affected only particular parts of the solution, and produced a deposition in one place, while there was none in another.

"3. These causes, acting differently in different situations, may have favoured the union of particular constituent parts in a certain proportion, while, at a distance, there may have been formed, from

the same elements, a combination of a nature considerably different. For instance, it is quite possible, that from the same general solution which deposited basalt in Saxony, may have been precipitated in America the extensive tracts of porphyry-slate observed by M. Von Humboldt . . ."

And so it goes for some pages: accounts of what "may very well be supposed" but which nobody happens anywhere to have actually seen.

One might quote not dissimilar language from unconscious and much belated disciples of Professor Abraham Gottlob Werner of this present year of grace. All are his children who talk better than they observe and invent what they do not see. We have under our eyes, wind and rain and waves, with sometimes earthquakes and volcanoes. With these—and time, which also we have observed—we have to explain the world. Who does that, inventing nothing, seeing no visions and dreaming no dreams, is of the Uniformitarians, with whose history and whose opinions the remainder of this volume is concerned.

It has taken the world a long while to learn to use Occam's razor on the rocks. Strabo did it, before our era began, affirming that "it is proper to derive our explanations from things which are obvious, and in some measure of daily occurrence."

Certain Moslem geologists also had the idea, even as early as the time of Harun-al-Rashid, of the *Arabian Nights,* who was contemporary to Charlemagne. But the Koran says the world was created in two days, and these men also had their troubles accordingly. Only with Hutton, and after him Playfair and Lyell, did men really come to believe that the earth, for a very long while indeed, has remained always just about what it is now. Werner, in particular, held diametrically the opposite opinion, trying always to make past stages of the earth as unlike as possible to everything that mortals see to-day. The early American geologists were all Werner's disciples—though not, in general, his pupils. Werner's views and Werner's habit of mind survived on this side of the water some while after both had faded out of Europe. Both, alas, survive still, and have to be reckoned with.

There can, then, be no real earth-science till *Wernerismus* is done with. If the world in past eras was not like the world now, then we men simply can not think about it at all. We can extend back into the past our present-day experience. But that is all we can do. So far as we think about something that we have never seen, we only think we think, using verbal formulas, "a tale told by an

idiot, full of sound and fury, signifying nothing."

The beginning of geologic wisdom, therefore, is to think of our world, if not from its beginning, at least from the bottom of the Paleozoic, which is all that ordinary mortals need concern themselves with in detail, as always throughout substantially what it is now. There were, to be sure, somewhat different animals and plants on its surface. But they all swam in the same sort of water; and they all, so far as can be made out, breathed the same sort of air, in spite of sundry ingenious speculations to the effect that they did not. There seem always, since the bottom of the Paleozoic, to have been about as many different sorts of creatures in the world as there are now, and about as many individuals of corresponding kinds. There never have been smaller things than bacteria, nor larger things than whales.

Meanwhile, the rivers have always run down off the mountains, and the sea has always been salt. There is no evidence that since the lower Paleozoic the world has ever been on the whole as cold as some parts of it are now, nor hotter than others are still. In short, if the human race, instead of being among the latest of animal species to appear on earth, had been absolutely the earliest of all the vertebrates, down at the very beginning of any

continuous and at all satisfactory life-record in the rocks, we have every reason to think that such super-early man could have managed just about as well as some modern savages get on now. To be sure, this super-early man would not have fruit; but neither, so far as we know, would he have wild beasts. He would have air and water, with unlimited shell-fish. They do not have fruit trees in Greenland and Tierra del Fuego now—and shell-fish are scarce sometimes.

CHAPTER VI

THE DIVISIONS OF GEOLOGIC TIME

One gets an idea of what all natural science was like, just about a century ago, by noting the scientific career of Professor Benjamin Silliman—"the elder Silliman," he is usually called—who, in 1802, was appointed instructor in the entire circle of the sciences in Yale College, was apparently the first American to hold a chair devoted to the natural sciences alone, and also the first American layman to be entrusted with the formal instruction of youth in the ways of nature in any American college.

Silliman, who at that time was just by his majority, was a lawyer by profession, recently admitted to the bar, and a tutor in law in the College. He seems to have known absolutely nothing about any branch of natural science, nor to have had any particular interest in any. But he was a promising young man, of thoroughly sound religious views.

Thereupon, as he writes, knowing the appointment was on the way, "Although I persevered in my legal studies . . . I soon after . . . obtained a

few books on chemistry and kept them secluded in my secretary, occasionally reading them privately. This reading did not profit me much. Some general principles were intelligible, but it became at once obvious to me that to see and perform experiments and to become familiar with many substances was indispensable to any progress in chemistry, and of course I must resort to Philadelphia, which presented more advantages to science than any other place in our country."

To Philadelphia, therefore, Silliman went, to enter the Medical School there: for in those days a Medical School was the only place where there was anything that could really be called science teaching. Nearly five entire months did this young lawyer spend in Doctor Woodhouse's laboratory. Then he returned to New Haven, to become the founder, in 1818, of the *American Journal of Science,* and on the whole, for the rest of his life, the most influential American teacher of geology of his time.

But if one thinks this is mere American provincialism, let him regard also the scientific career of Adam Sedgwick, D. C. L., LL. D., F. R. S., President of the Geological Society of London, Charles Darwin's teacher, and for fifty-five years, following 1818, Woodwardian Professor of Geology in Cambridge University.

Sedgwick was a clergyman by vocation, a Fellow of Trinity College and a tutor there in the inevitable classics and mathematics—and all he knew in 1818 about geology was that he had amused himself as a child by collecting plants, and had listened in on some lectures on the primitive physics of the time.

But Reverend Adam Sedgwick was out of health—lungs among other troubles—and needed outdoor life. The chair was becoming vacant which, in 1728, Woodward had founded by his will. So Sedgwick became a candidate—against a large field, for the Woodwardian Professorship at Cambridge was even then an academic prize. He won hands down, being obviously by far the best qualified man. His nearest rival, as Sedgwick said, ". . . had not the slightest chance against me, for I knew absolutely nothing of geology, whereas he knew a good deal—but it was all wrong."

What Sedgwick meant was this. He was really a very able man; and he was acute enough to see that the cosmological, theological, catastrophical, onion-coat era in geology was drawing to an end, when persons interested in earth-science "did not allow what few facts they may have possessed seriously to hamper the flights of their imaginations."

Uniformitarianism was in the offing, and the era of the professional geological surveyor with good legs and no imagination at all. So Reverend Adam Sedgwick taught his classes during his first Easter term. Then, the following summer, during the long vacation, he took his first look at British rocks. We still name divisions of the Lower Paleozoic as Sedgwick did, first of mankind.

It was men like Silliman and Sedgwick—gifted but untrained amateurs, about a quarter of them clergymen at that—who, during the first half of the last century, laid down the foundations of our present-day geological science. We of a century later still profit by their labors—and still expiate their mistakes.

The great problem was to classify the rocks—for classifying is always one of the first things that any science has to do with its material. Natural science, in fact, with at least half-truth, has been said to be "the art of calling different things by the same name."

Werner, as we have seen, based his scheme on mineral characters. For geology, in modern Europe, began as a department of mineralogy, which in its turn was an outgrowth of the practical necessities of the mining industry. But minerals give no clew to geologic age, for any mineral may form at

any time and almost anywhere. Proper geology begins when rocks are separated and named, not by their qualities, but by their positions above or below one another.

In short, proper geology begins with the geological map. The first geological map of any portion of North America was William Maclure's of 1809. The first, so far as is known, made anywhere on earth was William Smith's of 1799, of the district around Bath.

As for this latter worthy, if as Oliver Wendell Holmes said of the author of *America,*

"Fate tried to conceal him by naming him Smith,"

Fate met with indifferent success. He was a poor boy, a farmer's son, who got most of his education for himself. At eighteen—that was 1787—he became assistant in a land surveyor's office, and for most of the remainder of his life ran lines for canals and fixed the boundaries of estates, ending as he began, with a tiny pension from a grateful government. Incidentally, he had a hand in picking the building material for the present Houses of Parliament.

When he was past sixty, the Geological Society made him the first recipient of one of the first

honors of British science, the Wollaston Medal, the Council voting it unanimously ". . . to Mr William Smith, in consideration of his being a great original discoverer in English Geology; and especially for his having been the first, in this country, to discover and to teach the identification of strata, and to determine their succession, by means of their imbedded fossils."

The point is especially worth noting, because it is widely alleged just now among the non-scientific, that the whole idea of geologic ages and the whole practise of fixing the order of succession of strata from discontinuous districts by their contained fossils is arbitrary, and designed merely to make the facts seem to conform to the doctrine of evolution. So it is well to bear in mind that both the general idea of using fossils to identify strata and to fix geologic age, and the accepted divisions of geologic time with their order of succession, actually were established, a century ago, by persons who did not believe in evolution, and did believe in special creation and catastrophes. Moreover, of the men who, in outline, made our present-day stratigraphical geology, Sedgwick, Buckland, and Conybeare were clergymen, all strictly orthodox and two of them deans.

In short, the real facts are, that virtually all

that old group of British field workers whose labors outlined the whole paleontological proof of organic evolution were, when the *Origin of Species* appeared, either too old to alter their minds—like Sedgwick—or else, like Buckland, they had already gone to their reward. Of the four main lines of evidence for evolution in the animal kingdom, three were supplied with convincing data by persons who did not accept the theory.

"Strata" Smith got his medal and the accompanying grant at the hands of Sedgwick, who that year was President of the Society, and was also, in a very real sense, Smith's pupil. Said Sedgwick, concluding his oration, "I would appeal to those intelligent men who form the strength and ornament of this Society, whether there is any place for doubt or hesitation, whether we were not compelled, by every motive which the judgment can approve, and the heart can sanction, to perform this act of filial duty, before we thought of the claims of any other man, and to place our first honours on the brow of the Father of English Geology.

"If in the pride of our present strength, we were disposed to forget our origin, our very speech would bewray us; for we use the language which he taught in the infancy of our science. If we, by our united efforts, are chiseling the ornaments, and

slowly raising up the pinnacles of one of the temples of Nature, it was he who gave the plan, and laid the foundations, and erected a portion of the solid walls, by the unassisted labour of his hands."

All of which no doubt greatly pleased the old man, who had earned many times over his pupil's tribute. For us of the English-speaking world, modern geology begins with William Smith. We shall, therefore, best understand modern geological ideas by looking at British strata through Smith's eyes. Smith taught Sedgwick. Sedgwick taught Darwin. Darwin is one of us, knowing good from evil. So brief—only a century at most—is the history of any thoroughgoing geologic science.

"Strata" Smith was born—in 1769—near Oxford, and he earned much of his living in the district to the southwest, the district of Bath and Bristol and Salisbury Plain, southeast of Bristol Channel and the Severn, and he spent nearly twenty years in London besides. So he knew a somewhat wide range of country, knowing it intimately as one does who goes on foot looking for his bread and butter.

There was Smith's great luck. That district is geologically simple—obvious sea-floors, abundant fossils, for the most part of the Age of Reptiles, with the London Basin only of the Age of Mam-

William Smith, LL.D.
(1769–1839)

At the Age of Sixty-nine

"The Father of British Geology" and the first professional geologist and geological surveyor.

From Memoirs of William Smith *by John Phillips, London, 1844*

mals. The strata lie almost as horizontal as first formed, a little lifted toward the northwest when the Welsh Mountains came up, and so dipping gently to the southeast, just like the shingles on a roof, if one can imagine the roof tipped up at the eaves and down at the ridge-pole until the slope is a little bit the wrong way. One can, therefore, starting almost anywhere in south-central England, travel northeast or southwest and keep on the same formation. But if one travels southeast, then one finds each stratum dipping under the one next younger, and that in turn, a little farther southeast, under one still younger, until one comes to the London Basin where the rocks are youngest of all. For it goes without saying that where rocks lie almost horizontal and virtually undisturbed, those underneath must have laid down in the ancient sea before those on top of them. So one finds, in the Severn Valley, well down in the Age of Reptiles, the "Lias" rocks at the surface, where men dig the soil and quarry stone. Twenty miles southeast, the Lias shows only in the valley bottoms: the hilltops are the younger "Oolites." Another twenty miles, and the Lias is deep under ground, tapped only by the wells, the Oolites are on the valley floors, the hills are "Greensand." Another day's walk, and one is in the Chalk country of the Chiltern Hills,

with the Greensand underneath. Around London, they have to dig down to find the Chalk.

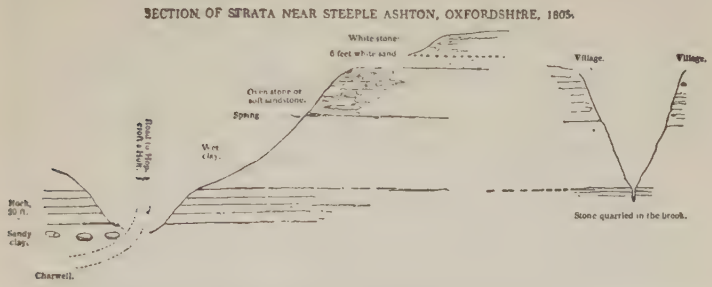
Or if one follows up a valley that enters the Severn from the London side, one sees the whole thing in the valley wall, everything edgewise, each rock layer in the cliff running under the one next younger, precisely as on the gable end of a shingled roof—except that the slope is the other way—one sees the shingles of one course underlying the course next above that was nailed on next after it.

That is the commonest of all arrangements of strata everywhere outside mountain regions. Strata rarely lie quite as they were deposited. For the most part, they dip under one another, and alter in the direction of the dip just about enough to make their relations as obvious as possible.

The New York strata are like that, Paleozoic in age, dipping gently southward from the older Adirondack country and the Canada hills, the oldest rocks therefore at the north and the late Paleozoic coal of Pennsylvania next above the youngest of them. The New York rocks, taken southward from the Great Lakes, are the norm for North American strata, as the British rocks southeast from the Irish Sea are the norm for European. James Hall mapped the one after 1836, following Smith, whose maps of the other, beginning with the

Tabular View of the British Strata of 1790 went forward to his complete chart of England in 1815.

Given, then, a fairly simple country with a half-dozen or so of different sorts of rock, sandstone and limestone and chalk and shale and the



From John Phillips, *Memoirs of William Smith*, London, 1844.

Sketch of Strata from William Smith's Field Note-book of 1805.

like, any practical quarryman needs only one glance to tell which is which, and every practical farmer knows what crops to grow on the soil that each provides. All that takes care of itself. The local indigenes always distinguish and name their local rocks with no help from any geologist.

They, in addition, along with the curious traveler, note the various layers of these known and named formations, piled one above another in the cliffs and hillsides and valley walls. What the indigenes and the curious traveler do not commonly notice, but William Smith did, is that whether one

takes the rocks across country, twenty miles for each alteration, or up and down in a cliff twenty feet for each change, in every district, *the order of strata is always the same.* If, for example, a particular black shale in one outcrop, lies above a particular red sandstone and below a particular white chalk in one location, then wherever those three rocks occur again, with all three visible, then the red sandstone will be lowest down and the black shale next and the white chalk on top. That will not always be true in a mountain district where most commonly the strata get much knocked about, but it will always be true in a flat country where the rocks are undisturbed. That was one thing that Smith saw especially in his wide wanderings over England. Werner also had seen it, though less clearly, sitting tight in his Erzgebirge.

One point, then, is established: Given a single district of rocks, not too much disturbed, we can fix the relative age of, let us say, the three or four layers that can be seen at once in one outcrop. We have, therefore, the order of age of these let us say three, because the older is always lowest down. Ten miles away, we find two of these same three rocks in their proper order; but the third and lowest is gone and a fourth, thus far unplaced, lies above the uppermost of the two familiar ones. Now we

know that our fourth stratum is younger than our third.

Another ten miles, and we find our first familiar third and our newly familiar fourth, with an unplaced fifth above these. Now we know that the fifth is younger still. Or perhaps we run the series the other way, picking up an older and older country, with its strata successively underneath the layers that we have already met. Thus, step by step, actually seeing each new formation above or below something that we already know, we build up a "geologic column," an ideal series that never shows itself to the eye in any single hillside or valley wall. But we can, in general, get the entire series, by traveling across country, either with or against the dip.

This is just what "Strata" Smith did, most patiently and carefully, for the whole of England, in most of a long life, being a professional surveyor, used to maps and notes and accuracy. Cuvier did the same thing for the strata of the Paris Basin. Sedgwick and Murchison straightened out the Welsh Mountains. James Hall put his life into the New York rocks. The Grand Canyon region is Powell's monument. Every spot of earth where the order of succession of the rocks is known has used up at least one man, who has known that dis-

trict, nook and corner, down to its single pebbles. One rather resents having persons who do not know one rock from another proclaim that Smith and Hall and Cuvier and Powell and the rest like them are quite mistaken in their views.

In brief, then, when William Smith died in 1839, the scientific world knew something that it did not know when he was born threescore and ten years before. It had learned from him to make accurate and detailed geological maps. It had learned also to say, with certainty: This rock has not the same geologic age as that—and we know which is earlier in geologic time.

There develops, however, mostly well within the last half-century, still another device for getting at the relative age of two strata, which can be applied anywhere, even if the two can not be found in place, the one visibly above the other in a cliff or valley wall.

Take, for example, a typical pudding-stone. The pebbles in it will be up to the size of a man's fist and perfectly recognizable for every describable quality that any rock can have. But if we find the same rock massive in another layer, then we know that the massive layer—a sandstone, let us say—must be older than the same sandstone as pebbles in the conglomerate. Evidently, there was

a sandstone ledge which got knocked to bits by the waves of some ancient sea, the fragments rounded to pebbles, and the pebbles recemented into the pudding-stone. So the order of those two formations is fixed, quite aside from all theory and all accident of location. A great deal of very precise work has been done of late in tracing out the genealogy of strata, the sources in one geologic age of the beach deposits and other derived formations of a later time. When, as often happens, there are twenty different sorts of pebbles in one pudding-stone, all distinct and recognizable, this method of discovering relative age may be carried very far indeed.

Moreover, in these days of elaborate scientific technique, a geologist is by no means content to take a naked-eye look at an imbedded pebble, or even to look it over carefully with a hand lens. He takes it into a laboratory, saws out a thin slab, grinds this down to less than the thickness of tissue-paper, and puts it under a compound microscope, commonly using also polarized light. He sees, then, not merely the pebble as a whole, but every sand-grain and mud-fleck in it. So the question which older rock each younger was made out of gets settled beyond anybody's dispute. It becomes even possible to tell how rapidly the primary rock

was knocked apart, how much the particles were rolled about, and whether the decay of them went on much or little, in the air or under the sea. A great deal can be learned about strata nowadays even when they do not show conveniently above one another in the hillside.

As it turned out, British geological science, in Smith's time and thereafter, was playing in luck. Wales and southern England, from Holyhead, let us say, straight through to London, exhibit a succession of strata, simple in the English plains, not too complicated in the Welsh Mountains, that carry through from the earliest of fossil-bearing rocks at the west side of Wales and the bottom of the Paleozoic, to the London Clay that is almost present-day river bottom. Everywhere, moreover, is the Glacial Drift. Buckland's "Red Lady of Wales" was the first of the Cro-Magnon skeletons.

When, therefore, by the middle of the last century, the British geologists following William Smith, had made up their complete geologic column, they found that they had, in outline indeed, but virtually entire, the history of the living world from about as far back as it will ever be carried up to the current issue of the *London Times*. The story is nearly continuous. There remained only the task of cutting it up into convenient sections,

as students of human history cut up the continuous flow of human events into Ancient History and the Middle Ages and Modern Times. This, British geologists did, promptly and thoroughly, taking their divisions from the conveniences of British rocks. Thus it comes about that, all over the world, the second order of the divisions of geologic time are for the most part either made-up words or British names. Everywhere on earth, Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Cretaceous rocks are whatever is taken to be of the same geologic age as portions of the British landscape.

NOTE: The divisions of geologic time can, of course, be had from any of the obvious text and reference books. For the reader's convenience, the list is here given in the appendix, edited to fit the topics of the present work.

CHAPTER VII

WHERE THE FOSSILS COME IN

We have then, early in the last century, William Smith mapping England geologically, and determining the relative ages of the strata of his geologic column by seeing with his own eyes the actual overlap as each older layer runs under the next younger. That point is settled.

But we have also, a generation later, James Hall mapping the New York rocks, and making out his geologic column for that district, by noting with his own eyes the overlap, like shingles on a roof, of the New York strata. And we have, farther west and later still, Powell, not yet Director of the United States Geological Survey, running the rapids of the Colorado and seeing his geologic column, a half-mile high, standing over his boat. Each, then, has his local geologic succession, his local geologic time. The problem is to correlate geologic age in three separate districts, with no visible overlap to span the ocean and the unknown lands between.

It was "Strata" Smith's great contribution to geologic science to find a way to do precisely this.

Smith was a land surveyor at a time when most of England was farm country. He fixed the boundaries of estates and fields. It fell also in his way to supply opinions as to their proper market price.

But the value of a farm turns a good deal on what will grow on it, and how much. The size of a crop, and the sort of crop that can be raised at all, turn on the character of the soil. The inherent productivity of the soil, and its special fitness for one crop rather than another, depend very directly on the underlying rock that is weathering away to make it, especially, of course, on the supply of calcium and phosphorus. Smith soon found that the rock strata down out of sight and unnoticed under a field, had a good deal to do with the price that could be asked for it.

Smith, then, being a remarkably sagacious and successful appraiser of agricultural land, took to noticing and mapping rock strata. He learned to recognize this formation or that by color, texture, hardness, and the rest of the somewhat obvious qualities that anybody interested would note. But Smith noticed something that almost nobody up to his time had observed, namely, that rock strata are identifiable, not only by color, texture, and the rest,

but also, and often far more easily and certainly, by particular fossils that occur in them.

Two shales, for example, may look just alike. They may both contain fossil shells that at the first glance may well be mistaken for one another. But the two shells are not the same species. So the rocks were not formed at precisely the same time nor under exactly the same conditions. The difference may determine whether the resulting soil is fertile or sterile, or whether one crop or another is best suited to grow on it. The chemical balance between soil and vegetation is most delicate, so that, very literally, one plant's food is another plant's poison. So "Strata" Smith took to watching the little fossil shells in the field outcrops, by way of guiding his opinion of what the field ought to bring in for rent.

Much of Smith's work, moreover, was running canals, mostly for shipping away British coal to British mills. He had, therefore, to know, and often to know at a glance, which strata in British hills will hold water and which will let the canal run dry. He surveyed for coal shafts. Certain British land-owners grew rich by taking Smith's word that certain inconspicuous shell-fish fossil in the rocks meant coal far down out of sight; certain others paid dearly for digging where Smith warned

them it would be no use. He was especially successful in draining lands by going back into the hills, tapping the water-bearing stratum, and catching the trouble at its source. Conversely, he supplied several towns with water, by tapping streams that were flowing past them underground. He knew, in short, minutely, what was inside the earth; and his knowledge seemed uncanny to his neighbors. But he was always the practical man; and he invented the profession of geological surveying, of which he was the first practitioner.

Smith was then, a most painstaking and accurate man—as a surveyer needs must be—and a man of uncommon business sagacity besides. But Smith was also a great genius. Among the three, Smith first saw and then proved one of the great basic truths of all stratigraphical geology: *Each geologic stratum that contains fossils tends to contain also a unique and characteristic group.* In other words, and specifically, if a layer of white limestone, let us say, lies under a layer of black shale, and over the black shale lies another layer of white limestone, the two limestone layers may be of exactly the same texture and the same thickness and in all respects completely indistinguishable—*but they do not, in general, have precisely the same fossils.* Smith tested that principle over and over again in all

parts of England. A thousand other geologists in all parts of the world that have been explored at all have tested it a thousand times more. It always holds.

But it need not, theoretically. Suppose there were only one sort of limestone-making creature in all the earth, created in the beginning, unaltered afterward. Evidently, all limestones, if they contained fossil shells at all, would contain the fossil shells of this particular creature. All limestones would, then, look alike; and the only way to tell two of them apart would be to get them together in the same landscape.

Just about this was, indeed, the actual situation during the Werner epoch, when the looks of one stratum served to match it with another, instead of the fossils in both. There are for example, the famous Old Red Sandstone and New Red Sandstone of the British Isles. Naturally, two red sandstones look about alike: and so far as looks go, either might be the other. But the "Old Red" is Devonian, of the middle Paleozoic; and one finds in it, or just above or below, trilobites, and the strange five-foot lobsters that are named eurypterids, and the ostracoderms, fish on one end, crab on the other, that it was lately the fashion to suspect of being the long-sought ancestors of the vertebrates.

But the "New Red" is much later, part of it very late Paleozoic and part Triassic. It then will have for its fossils, not trilobites and ostracoderms and eurypterids, but amphibian remains, a few primitive insects, and most especially, those remarkable footprints of great dinosaurs that have excited men's wonder for a hundred years. None of these will appear in the Old Red; all the characteristic remains of the Old Red will be absent from the new. So the two are always distinguishable, if one has all the data.

Or suppose the number of limestone-building species were small, and they all had lasted through from the first creation. Then, obviously, likeness or unlikeness of fossil contents between two limestone layers would prove little. If they were alike, they rather had to be, the possibilities being so few at best. If they were unlike, even then they could not be so very different.

But the actual facts turn out to be precisely the opposite. The number of limestone-making species, or of species that occur in limestones in enormous numbers, is itself enormous—up into the tens of thousands. In addition, so far are species of shellfish from lasting through from their first creation, that as a matter of fact they may alter completely, several times over, from top to bottom of a single

cliff. Obviously, then, if two limestone layers, no matter how far apart, contain numerous fossil creatures, of numerous species, alike in the two strata and all unique, the chances get up into the thousands to one that the two strata are not so very far apart in geologic age. When, however, one finds, not two strata, but all the strata of an entire geologic column from one district matching accurately, in order, the corresponding members of the other local column, then only the wildest-eyed of skeptics can doubt that the two are substantially contemporaneous. So we know how Smith's geological column in England and Hall's in New York and Powell's in Arizona match up together, because we know, layer for layer, just how the fossils do or do not correspond. So we know that the Welsh rocks start with the Lower Paleozoic and grow younger southeastward, and that the New York rocks start with the Lower Paleozoic at the north and grow younger south, and that the walls of the Colorado Canyon start with the Lower Paleozoic near the bottom and grow younger upward. We know also, step by step, how fast time and rock-formation went in each district, and which layer in one section is the closest match for which in each of the others.

One dwells on this because the matter is both

important and widely misunderstood. We could not correlate geologic age outside a single district, if the number of fossil creatures were not enormous. We could not do it if these abundant fossil animals and plants did not alter rapidly and completely within a short vertical distance in a single cliff. We could not do it so well if a creature, once extinct, ever reappeared. We could not do it so certainly if we did not have abundant remains of simple plants whose spores are blown a thousand miles by a single storm, of small land shells or edible seeds that a migrating bird carries in crop or on mud-encrusted feet on the way from Labrador to Patagonia between nestings, of free swimming sea-things that travel through the seven seas at their will. Mostly though, as a matter of practise, we depend on the shore-dwelling mollusks and brachiopods and trilobites, that have hard shells, live in countless numbers just where they most easily get buried over by the shore wash, and make their way along the beaches and offshore flats, a few hundred miles in a human generation, as the common European periwinkle, introduced at Halifax in 1857 has been slowly making its way southward along the New England coast, reached Cape Cod some years ago, and is now moving still farther down along the shore. This sort of thing has been

happening everywhere throughout the history of life on earth. Where it occurs, even without overlapping strata, we prove relative age and synchrony within a few millennia at most.

All this, "Strata" Smith, before the nineteenth century was a quarter done, made possible by finding out that the fossil species in any stratum tend always to form a unique group. So the unique assemblage of creatures once alive proves identity in the rocks that are now their sepulcher.

Practically, of course, all this is by no means so easy as it sounds in theory. Some creatures have survived a long time and run through many formations. These, therefore, are useless for identifying any particular stratum. But on the other hand, many fossil things have a wide range horizontally and appear in well-separated districts, but have a short vertical range. These, therefore, become "index fossils." If they appear at all, they date their surroundings, all very much as figure and pattern and material and ornament dates, for the expert collector, building or weapon or costume or vase. There are published lists of index fossils as there are published lists of the hall-marks of old smiths. Sometimes a district waits twenty years unplaced. Then the right fossil turns up—and all guesses but one are known to be wrong. All this

is highly specialized expert work nowadays so that the curator in one sort of museum has to know at a glance each separate tooth of some long-extinct beast, as he of another sort knows the characteristic brush-stroke of some long dead artist. Possibly they both make mistakes; but only another expert like them can find either of them out.

One gets, perhaps, the best idea of how an expert paleontologist goes to work to date the rocks of a district new to him, by imagining oneself to be interested, let us say, in old houses, finding oneself in a strange village and trying to date the dwellings along an old street.

If one were interested in old buildings and were something of an expert, one would know just about when various items of house-building came in and went out. Bull's-eye glass gave way to the cylinder-blown form at about such a year. At about such a date the manufacturers stopped making a white glass that afterward turns blue and got one that stays white. The machine-cut nail was invented in such a year. The wire nail replaced this, so and so. If one were a good deal of an expert and knew his district rather minutely, one would recall that a certain brick-yard ran out its clay bank in such a year, and all the local brick thereafter came from a different maker and has minute but recognizable

differences. There are styles in mantelpieces and doors.

So it would go. There would be local fashions. Some communities would alter faster in one particular and slower in another. A prosperous town would react quicker than a poverty-stricken one. Changes tended, in the old days, to travel somewhat faster up and down the coast than across country inland. One thing with another, an expert in old dwellings, in a very short while, will place an ancient dwelling within a decade or two.

The expert paleontologist works in the same way. His nails and glass and standing finish are bones and shells and teeth. By means of these, he will guess the date of a not too ancient rock to within its correct "epoch." That, in geologic time, is about as close as decades in colonial history.

This whole question of the relation of fossils to strata and to geologic time and to the order of events in the history of the earth is so fundamental to at least two great branches of natural science that it may well be looked at from still another side.

Take, for example, any one of the early British geologists—Sir Roderick Murchison, let us say, who for years was Sedgwick's field partner and gave the name, Silurian, to certain Welsh rocks, in the first half of the Paleozoic, when the true fishes

were just getting their start. A man like Murchison, then, spends years afoot, in his district, sees every ledge and outcrop in it, collects samples, makes notes, draws maps, constructs sections, spends the winter months in reading up everything that has been written on his problem and disputing with everybody else who has ever been over his country. Each summer he goes back and checks up on the rocks all the inspirations and theories and facts that have come to him indoors.

By and by—Darwin, it will be remembered, digested the *Origin* twenty years before he brought anything to print—Murchison, as we are supposing it is, writes a paper for the Geological Society, proposing that the name Silurian shall be applied to certain strata lying above such and such an outcrop on such and such a hillside—which everybody knows by sight and can locate in the dark—and below another equally familiar rocky ledge in some other Welsh glen. So far, there is no theory involved.

Sir Roderick, we are supposing, then continues with the information that those stratified rocks, as thus defined by their place in the Welsh landscape, do as a matter of fact, contain certain fossils, which he has dug out, pictured for convenient reference, deposited in such and such a collection, and merely

for identification has named so-and-so. Murchison's account of his Silurian strata stands up under criticism. The name Silurian is adopted for those particular rocks. They are said to be of Silurian age, and the shells in them are called Silurian fossils. There is no theory there.

Meanwhile, Sedgwick has been doing exactly the same thing for another bit of the Welsh landscape which is his special field, calling that "Cambrian" and listing the fossils in it, seeing with his own eyes, in actual hillsides, that his "Cambrian" strata do lie underneath Murchison's "Silurian." Somebody else has done the same for another lot of rocks farther east and called them and their fossils Devonian. Everybody who troubles to look, sees that "Devonian" rocks overlie "Silurian."

We have, then, three groups of fossil clams and snails and trilobites and brachiopods, no species of them—speaking broadly—occurring in more than the single system, all displayed in museum cases and pictured in reports. Do we know, all theory aside, which of the three fauna is oldest and which the most recent?

We certainly do! We know that the creatures that we have named Cambrian lived earlier on earth and became extinct sooner than those which we have called Silurian, for the simple reason that the

rocks out of which somebody took the trouble to quarry the Cambrian fossils lie visibly underneath those which furnished the Silurian group. We know, in like manner, that the Devonian group is younger than the Silurian, because it, in its turn, lies visibly higher up.

In short, given any number of fossil species from the rocks of the same district, we know the order of their age, because we know the difference between up and down.

By and by comes along James Hall, head of the New York Survey. He also finds rock strata, gives them local names from the New York towns, sees which lies next above and next below all the rest. There is no theory there.

He also digs out fossil mollusks, trilobites, and brachiopods. He compares these minutely with British forms. Then he finds—what he might or might not expect in advance—that certain groups of these, out of certain designated rocks, match, exactly or closely, groups out of British reports. So Hall, in New York, assigns the identical names to the corresponding groups of animals and to the rocks out of which they came. There are Cambrian rocks up toward the Canadian line: a belt of Silurian strata lies south of Lake Ontario: the lower half of the state and over into Pennsylvania is De-

vonian. The significant thing is that the rocks with Cambrian fossils always lie underneath those with Silurian: the Silurian lie always lower down than the Devonian. Anybody can see that they do, just by looking at them in the valley walls.

That is not, however, the whole story. All over the world, wherever expert geological surveyors have traveled, they have found almost always somewhere in each large district, some formation with such fossils in it that it can be set somewhere in the British series, and said to be Cambrian, Silurian, Devonian, or the like. But everywhere on earth, in a flat country outside the mountains, where the strata have not been disturbed by mountain-building, Silurian fossils are always underneath Devonian and above Cambrian. That is not a matter of any theory. It is a matter of fact.

There is another fact, still more significant.

Strata are identified and named for the most part by their small, hard-shelled sea-creatures. It must needs be so, because only the little swarming things are numerous enough for one to be sure to find them where there has been any sort of life preserved. Moreover, only small creatures with hard shells, like snails and brachiopods, are likely to be preserved whole and identified easily after accidents and the lapses of time. Finally, we have to

rely mostly on sea-creatures, because sea-creatures, vastly more than land animals, get buried up and preserved; and also because, while there are many lands, there is only one ocean, and the animals and plants of the sea tend to be more or less alike the world over, instead of being so very different from place to place as land things are.

In short, speaking broadly, strata are identified, given their place in the general geologic column, assigned their date in geologic time, ultimately on the strength of the resemblances of the shell-fish in them—and the proper fish as well—to the shell-fish and the sea vertebrates of the British Isles and western Europe. These matters are settled strictly by points of fact. They do not involve any question of theory whatever.

But the noteworthy matter is, that after we have fixed the time succession of all the rocks of earth by their positions above and below one another and by simpler water-creatures fossil in them—the snails and clams and trilobites and the like—it then transpires, after all this is done, that the succession of the higher creatures in geologic time corresponds exactly to what we should predict from the general theory of organic evolution.

The first amphibia, for example, are older than the first reptiles. The first reptiles are older than

the first mammals. The primitive "non-placental" mammals are older than our own sort. The primitive fishes without hard internal skeletons are older than the "bony" types that we get now. The three-toed horses are older than our single-toed stocks. The pines and firs are older than the broad-leaved trees, but younger than the ferns and mosses. The dinosaurs are older than the birds. The toothed birds are older than the toothless sorts we know. The snails and clams are older than the cuttle-fishes and squids. One could go on for pages, and then pages again. We ourselves have not been long on earth as time goes—and the apes are older than we.

It has been said many times of late years—in unscientific circles—that all this arranging of strata in geologic columns and species in geologic time is factitious, done out of whole cloth, to make the order of succession conform to evolutionary theory. But fact is precisely opposite. For, in the first place, no man could possibly arrange factitiously fifty or a hundred evolutionary series—the number is at least that—all independent, with dozens and scores overlapping in the same rocks, and have them all come out to suit any theory. If he got one right, the rest would have to be wrong—unless the several independent series of ancestors and de-

scendants actually did appear on earth in the order supposed.

In the second place, as a matter of fact, most of the fundamental arranging of formations in geologic time is done either directly from the rocks in the actual landscape, or else from three main types of small shell-fish, that had already completed their evolutionary progress before the record of continuous life begins, and have merely altered since, without advancing. We prove evolution by way of just those fossil creatures that have least evolved.

In the third place, the whole thing was done, in all its main essentials, by men who did not in the least believe in evolution, at a time when fewer persons did believe in evolution than ever before or since.

All this is not theory. It's history and fact.

CHAPTER VIII

WHAT IS INSIDE THE EARTH

WHAT lies inside the earth, underneath the pastureland and often-labored fields, is a problem that must always have piqued men's curiosity since the first curiosities of mankind about anything. It piques our curiosity still—and the problem is still unsolved.

All prescientific persons seemed to have reasoned about this problem in the same way, and to much the same result. Most districts contain stratified rocks. Most stratified rocks contain limestone layers. Most limestones contain caves, dissolved out by the ground-water with the aid of the soil acids and the carbon dioxide of the air. There are such caverns miles in extent with galleries on a dozen levels. There are districts, several of them in North America, where all the small and medium-sized streams run underground.

Men are always interested in caves. Caves are creepy and mysterious. They are also highly convenient for pirates, smugglers, bandits, persons

shipwrecked or defeated in battle, shepherds whose flocks have been threatened by robbers or caught in a storm; and long before men had thought to dig the villainous saltpeter out of the bowels of the harmless earth to the ending of many a good tall fellow, they scraped the saltpeter off the floors of caverns to cure their meat. But in the days of smoky torches, nobody ever went to the end of a big cave.

As usual, men imagined what they did not see. There was the cavern, vast and unexplored. Who knows how far even vaster caves may honeycomb the earth? Thus there arises everywhere an enormous mass of legend concerning hollow mountains, cities underground, cave-dwelling gnomes and other half-human things, and more than all, the subterranean Realm of the Dead—Tartarus and Sheol and the Elysian Fields, where there is one fate to the righteous and to the wicked, and the mighty men of old have gone down with their weapons of war and have laid their swords under their heads.

Afterward, about the beginning of the Christian era, the good man—for various complicated and interesting reasons that are partly political—shifts his final abode from the underworld in the hollow earth to the floor of heaven. There are, of course, also the Terrestrial Paradise, and the

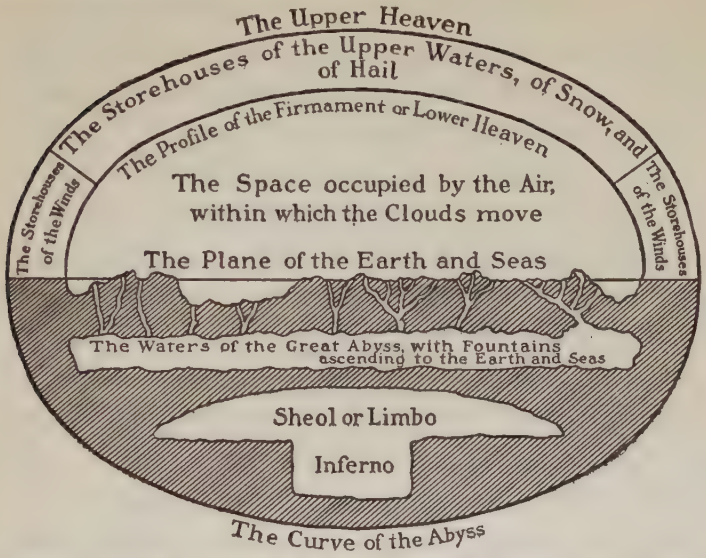
Blessed Isles, and the World-under-the-Waters. But in general, in the Mediterranean country, the hollow earth contains Hell, and the blessed good go to dwell with the gods in the land above the solid sky. Thus Dante, about 1300, puts the nine circles of Hell in the conical hollow reaching to the center of the globe made by the impact of Satan flung out of Heaven, after the manner of the shell craters of the late war. Since 1925 there has been printed in Philadelphia an account of the geological results of the rain of fallen and falling angels on the post-Carboniferous earth.

But given a hollow earth, men are bound to speculate as to what besides Hell is in the cavity.

Woodward said: Water. On the whole, most of his contemporaries late in the seventeenth century agreed with him, even to making the whole earth one vast, thin-shelled cavern occupied by the waters which became Noah's Flood. But Whiston, vastly impressed by the great comet of 1680, opined that the condensation into water of a comet's tail was the chief source.

This general idea of great reservoirs of water deep down in the earth is really very old. One gets it, for example, in the Great Deep, "the waters that are under the earth," of the Babylonian-Hebrew cosmology; and because the notion has, there-

fore, the infallible authority of Holy Writ, it has been a datum of all earth-science well up to the end of the sixteen-hundreds.


The Upper Heaven
The Storehouses of the Upper Waters, of Snow, and of Hail
The Profile of the Firmament or Lower Heaven
The Storehouses of the Winds
The Storehouses of the Winds
The Space occupied by the Air, within which the Clouds move
The Plane of the Earth and Seas
The Waters of the Great Abyss, with Fountains ascending to the Earth and Seas
Sheol or Limbo
Inferno
The Curve of the Abyss

From G. Schiaparelli, *Astronomy in the Old Testament*, Clarendon Press, Oxford.

SCHIAPARELLI'S INTERPRETATION OF BABYLONIAN COSMOLOGY

Other authorities put Sheol above the Great Deep and make the land to float on the Waters that are under the Earth. Some Babylonians, also, curved the upper surface of the land, approaching the Greek notion of a spherical earth.

The earth, then, contains great masses of water, which, following out Babylonian opinion, connect on the one hand with the sea; and on the other, far away from the ocean, by way of "the fountains of the Great Deep," well up as springs and lakes.

The idea is not at all irrational. Babylon and

Egypt and Persia are dry countries. There is rain in the mountains—where nobody ever goes. But the springs and wells and water-holes are obviously fed from below. There is no reason for supposing that their water comes from the mountain rains. There are many reasons for thinking that it does come underground from the sea.

Such was the general opinion in Europe during the Middle Ages. Rain does, indeed, in most of Europe, obviously water the earth. But the great rivers, and all the springs, are taken to be fed by the fountains of the Great Deep, which in turn take their supply from the sea. How the salt sea-water becomes fresh, is too small a point to bother anybody in the age of miracles.

Albertus Magnus, who was the greatest scientific personage of his time—he died in 1280—held this theory of springs. So, too, did his contemporary St. Thomas Aquinas, who was not so much of a scientific man but is still more famous as a theologian.

By Ray's time, late in the sixteen-hundreds, the question of where spring-water comes from was an acute scientific problem. Ray himself, who was a natural-born skeptic, and therefore, on the whole the most scientific person of his day, inclined to the rain hypothesis. Edmund Halley—he of the

famous comet, who paid for Newton's book on gravitation—had a theory that "Vapour," a sort of universal British fog, rather than rain or what we now call ground water, feeds the springs. Hooke—he of "Hooke's law," plague of the present-day schoolboy taking physics—reckoned that since salt water is heavier than fresh, the pressure of the sea might force water through underground passages, and out through the hillside springs to feed the rivers. In fact, it was not until well into the eighteenth century that the point was really settled, that all the water circulation of the globe is from the sea to the mountains by way of vapor in the air, not by way of caverns and passages in the earth. "The waters that are under the earth," it turns out, are flowing the other way from what Babylon supposed. The Great Deep and its fountains have dwindled to water-moistened rocks.

But something else, at least as notable as spring-water, comes visibly out of the earth—lava, namely, hot and melted. Perhaps, then, after all, the hollow earth is not filled with liquid water but with liquid rock. The great Leibnitz, along with others, took up this idea in his *Protogæa,* which came out in 1680, almost a half-century before Woodward's death, seven years before Newton published on gravitation.

All that was in the early days of physics—Galileo's work on falling bodies, which marks about the first real advance over Greek ideas, was of *circa* 1590. A philosopher, therefore, of those early times, had not to bother his head over little things like tidal strains and where his hypothetical temperatures are to come from. So Leibnitz went ahead, fancy free, with a theory of the earth that still prevails pretty universally among persons who have missed high-school geography.

Leibnitz imagined a liquid world, very hot of course, and with all its rocks melted up, that has gradually cooled down to its present temperature; and will, presumably, continue to advance in the same direction toward a frozen end. There is, to be sure, even now, scanty direct evidence for any such opinion; and it may well be that our old earth was never hotter nor wetter than it is still. Indeed, we happen to know that there was a glacial period down at the very botton of the Paleozoic, almost at the beginning of any satisfactory life-record; and while we do know that the distribution of temperature over the earth has shifted back and forth, its average climate, inside and out, equator to pole, seems not to have altered significantly since the earliest vertebrates appear. But Leibnitz knew nothing of all this, and so imagined what he liked.

Details are not unfamiliar, being quite in the non-scientific tradition. The molten earth, it is still imagined, froze over on the surface to a thin crust. So when the rain fell on this, the water promptly sizzled off again to form vast and all embracing clouds of hot fog, that obscured the sun and made a sort of cosmic hothouse for the coal plants. To be sure, the actual coal plants, besides being late Paleozoic and hardly older than half mammal-like reptiles, also hint a little at a dry climate, not a wet one, being apparently the swamp vegetation of a flattish country, that grew up into rather cold and dry air. But that was all long before the days of compound microscopes and structural botany, and a sixty-foot tree fern quite naturally went to prove the cosmic Turkish bath, in spite of the rather obvious fact that nowadays all the great bog and fen country of the earth is rather in cold climates than in hot.

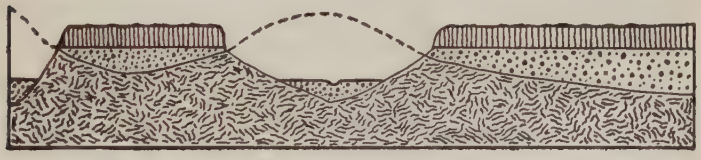
All theory aside, however, there is not any doubt that there is liquid rock in some places inside the earth. We know it is there, because it comes out.

There are, in the first place, volcanic eruptions. These commonly begin by blowing up an old mountain and spreading its fragments over a thousand square miles of landscape. Krakatoa, for example, in 1883, shot skyward half a fair-sized island, and

the finer particles of it were a couple of years in settling back to earth. After that comes, usually, a quiet welling up of molten lava, that first brims the crater, then breaks through the crater wall near the top, and streams down the mountainside, sometimes as fast as a man can run. Such a fiery river may flow twenty miles before it freezes. One in Iceland made ninety. A few hundred such, from repeated eruptions sometimes centuries apart, help to build such mountains as Vesuvius or Etna—the former a little mountain, the latter ten thousand feet—or the great Andean cones that beat twenty thousand and are among the loftiest summits of the earth. The Hawaiian Islands are mostly lava; Hawaii itself is nearly a hundred miles across and stands thirty thousand feet above the Pacific floor. Iceland, also volcanic, is ten times as large.

But Aconcagua and Mauna Loa are but hand specimens compared with the mass of rock that comes from a "fissure eruption," where no cone forms, but the lava wells forth from a long crack in the earth's crust and simply floods the country. The Snake River Plateau covers half of Oregon and Washington, crosses the entire width of Idaho, and comes southward a hundred miles into California—some two hundred thousand square miles in all, the area of twenty-odd states like Massa-

chusetts. The lava, in places, is four thousand feet thick, so that it buries the smaller mountains of the old landscape as paint covers the grain of smooth wood. All this, to be sure, did not happen at once; in fact, it took no small part of the middle Tertiary. But there are single flows two hundred feet thick, that once were lakes of melted stone. A similar outflow in the Indian Deccan is even vaster than that of the Snake River district; while another in Brazil and Argentina is larger still.



LAVA-CAPPED MESAS

Dotted lines show the old surface of the district, with two valleys floored with stream gravels. Lava flows partly filled the old valleys. The hard lava resists decay; and new valleys, with their stream gravels, form in place of the old hills. The lava remains as a cap on flat-topped hills. Beneath the lava are the old stream gravels, now ofttimes gold-bearing or fossiliferous.

That, for North America, the greatest volcanic activity of all geologic time should have occurred so late as the middle of the Age of Mammals, so late, apparently, that even our own human stock had by that time split off from its primate relatives, makes interesting commentary on Leibnitz's old theory of a cooling globe.

With lava flows and all volcanic activity dis-

tributed on the whole somewhat uniformly throughout known geologic time, and on the whole also, somewhat uniformly over the earth, the older rocks will, naturally, contain more frozen stuff and less waterlain than the more recent. This is inevitable, because the lava flow comes up from underneath, passes through the lower and older rocks before it reaches the higher and younger ones, and if it freezes on the way adds its mass to whatever it went through. So an old rock has more lava simply because it has more time. But the lava introduced into an old rock, may itself be quite recent.

Thus it comes about that the more ancient rocks of the world tend to be lavas and granites and related sorts, or their much altered and modified results. From this only, comes the widespread notion that granites are always old, and the old notion that granites and the like are the earth's original crust. There is really no reason for thinking that the older rocks were in their day in the least different from the mud-flats and sand beaches and the soil that the farmer plows, combined with just such lavas as in certain districts now run down off the mountains over the farmer's land. All things are as they were from the beginning of the Paleozoic; and there is nothing new under the sun.

One can, therefore, almost anywhere, except in

the most recent deposits, find abundant signs of volcanic activity.

Commonest in most districts is the dike, a band of rock, usually rather darker than its surroundings, that cuts through the country rock in sheet or strips, according as one sees the side or the edge. Most often, these dikes stand nearly up-and-down, the lava following a vertical crack as it comes up from below toward the surface. The dike is, of course, the last bit of the flow, that froze in place.

Such dikes may be a hundred feet across, or they may be no thicker than cardboard, the last bit of a long tongue that was opening out a crack and flowing into it; and they run across country, sometimes a score of miles, and even one, two, and three hundred. Nearly always, one can make out at the contacts with the country rock that the hot lava has baked the sides of the old crack, for a fraction of an inch or whole inches; and on the other hand, the dike itself is likely to show faint banding where the cold wall cooled the sides of the lava faster than the interior. Where the soil has been stripped off, as on a sea cliff, these dikes sometimes appear fifty or a hundred to the mile, and so varied in direction that the newer cut the older at all angles, and often still a third cuts two more, the relative ages being obvious from the way the cracks

run. But oftentimes the dikes fill nearly parallel cracks; sometimes more than a thousand in ten miles. There are really vastly more of these old lava flows in the rocks than one realizes, for the lighter-colored dikes look almost exactly like hard sandstones, and a granite dike cutting a granite ledge hardly catches the eye at all.

Such crack-filling lavas are sometimes harder than the country rock, so that when this weathers down to soil and gravel, the dike stands up like a wall—hence the name "dike." The famous Devil's Slide in Utah is precisely this. Quite as often, though, the dike-stone weathers more easily than the rock around it. The sea waves, in particular, often cut fast into lavas; with the result that along a rockbound coast, one encounters numerous chasms that run back from the water, sometimes as if a great saw had cut into the shore-line. Commonly, in these clefts, one makes out at low tide the dike-stone on the ocean floor. Nearly always, at the shore end, there is the old dike not yet broken out by the waves.

There are, besides, what are really horizontal dikes, such as, on a small scale, the miners call "sills." Naturally enough, when a few cubic miles of melted rock are working up through the earth's crust, not all of it will find vertical crevices. So it

Devil's Slide. Utah

Dikes filling parallel joint-cracks and more resistant than the country rock.

Photograph by W. H. Jackson

has to run sidewise between the beds of the older rocks, forcing these apart and filling the space. There, in time, it freezes. The result is a vast horizontal sheet, commonly of dark basalt, with the country rock above and below. The famous

DIKES, SILL, AND SURFACE FLOW

At the left, a feeding dike below; three ordinary dikes above, that follow parallel joint cracks. Through the middle, a sheet of lava intruded between strata. At the top, a surface flow of lava with its feeding dike.

Giant's Causeway on the north coast of Ireland beyond Belfast is an example. So, too, are the almost equally famous Palisades of the Hudson River, on the west side northward from New York City; and such intruded lava sheets are rather common on a small scale in all fairly old stratified rocks. They look like surface flows of lava, afterward buried. One tells the two apart, by the circumstance that a surface flow can not bake the rock over it, while an "intrusion" always must. So the New Jersey trap is an intruded lava sheet; but the Connecticut trap, of the same age and almost exactly like it, is a surface flow.

As for the granites, these are only light-colored, rather acid, and stiffish lavas, of high melting-point, that do not flow freely enough either to reach the surface or to form extensive thin sheets. So they form cisterns underground, melting out spaces for themselves rather than forcing cold walls apart.

PALISADES OF THE HUDSON

The strata dip gently westward away from the river. A lava sheet, intruded into them and jointed into columns as it cooled, now forms a nearly vertical cliff along the river.

Therefore, cooling deep underground, they cool slowly—hundreds of years, probably, for a mass only a few miles across—and so have the large crystals that characterize all rocks of the granite type. There are entire mountains that are nothing but these granite bosses with the overlying rocks worn off, the White Mountains of New Hampshire for example. Many great mountain ranges have some sort of granite cores through their entire length.

Altogether, then, the quantity of visible rock in the earth's crust that has obviously been melted and then frozen, is really very considerable. In

fact, in some districts—as for example in the White Mountains and the central portion of the Adirondacks—the whole country is just granite, masses belonging to one geologic age intruded into bodies of another, both cut by dikes of various later times.

No wonder then that men have widely held that the granites are the cooled surfaces of a once-molten globe, and that the earth's interior is still fluid.

Even so, the opinion that volcanoes tap a liquid earth, is both less ancient and less widely held than is commonly supposed. There was always the contrary hypothesis that the mountain is actually on fire—perhaps a mountain of burning coal. The notion was not unreasonable before Lavoisier had made out the true nature of all combustion. Moreover, volcanic gases do actually burn.

Thus, to quote once more the indefatigable Ray, to whom nothing natural was foreign:

"But as for those Earthquakes that are occasion'd by the Burning of *Vulcano's,* they are, I conceive, of a different Nature. For in them the Fire burns continually, and is never totally extinct, only after the great Eruptions, in which, besides Smoak and Fire, there is an Ejection of abundance of Ashes, Sand, Earth, Stones, and in some Floods of melted Materials, the Raging is for a time qualified; but the Fire still continuing, and by Degrees

increasing in the combustible Matter it finds in the Hollows of the Mountains, at last swells to that Excess, that it melts down Metals and Minerals where it meets with them, causing them to boil with great Fury, and extending itself beyond the Dimensions of the Cavities wherein it is contained, causes great Succussions and Tremblings of the Earth, and huge Eruptions of Smoak, and casts out such Quantities of Ashes, Sand, and Stones, as we just now mention'd; and after much Thunder and Roaring by the Allision and Repercussion of the Flame against and from the Sides of the Caverns, and the Ebullition and Volutation of the melted Materials, it forces out that boiling Matter either at the old Mouths, or at new ones, which it opens where the incumbent Earth is more thin and yielding. And if any Water enters those Caverns, it mightily increaseth the Raging of the Mountain. For the Fire suddenly dissolving the Water into Vapour, expands it to a vast Dimension, and by the Help thereof throws up Earth, Sand, Stones, and whatever it meets with. How great the Force of Water converted into Vapour is, I have sometimes experimented by inadvertently casting a Bullet in a wet Mold, the melted Lead being no sooner poured in, but it was cast out again with Violence by the Particles of Water adhering to the Mold, suddenly

converted into Vapor by the Heat of the Metal."

Altogether, then, especially in his idea of the part that water plays in a volcanic outburst, Ray, the naturalist had very much sounder and more modern notions than had Leibnitz the philosopher. That he thought rocks will burn is not to his discredit, for the opinion is very ancient and the beginnings of chemistry were still a hundred years away. In fact, the general notion of the Earth and Heaven finally destroyed by fire is both Stoic and Christian.

Thus Ovid in a seventeenth-century rendering:

". . . Besides by Doom
Of certain Fate, he knew the time should come,
When Sea, Earth, ravish'd Heav'n, the curious Frame
Of this World's Mass should shrink in purging Flame."

And Lucian:

"If now these Bodies want their Fire and Urn.
At last with the whole Globe they'll surely burn.
The World expects one general Fire: and thou
Must go where these poor Souls are wandering now."

So there were, in the seventeenth and eighteenth centuries, two rival theories of volcanoes and the earth. Leibnitz taught that the earth is cooling down. The Stoic tradition favored an earth getting ready to warm up.

CHAPTER IX

THE LESSON OF THE EARTHQUAKE WAVE

WHETHER the earth be hollow or not, one point is certain—its volcanoes do not tap the central cavity.

Take, for example, such a pair of craters as Mauna Loa and Kilauea on Hawaii Island. The two were originally separate, each a little peak, built by successive eruptions, rising from the floor of the deep Pacific. Each grew, and in time the islands joined, with the peak of Mauna Kea added on. In fact, the whole Hawaiian group is nothing but lines of volcanoes strung out on four nearly parallel straight cracks that together are more than a thousand miles long. Whoso can wait long enough should see there only one land-mass.

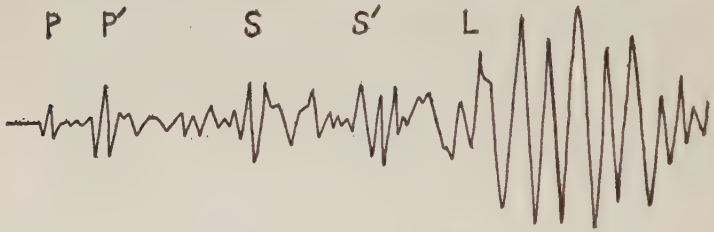
Mauna Loa is 13,675 feet high. Kilauea is only about four thousand; and the two are only twenty miles apart. So the liquid rock stands nearly two miles higher in the large peak. Moreover, the lower crater is in a state of chronic mild activity. But the higher outlet is highly temperamental,

sometimes doing almost nothing, and sometimes sending out streams of lava that have been a hundred feet thick, more than five miles wide, and nearly fifty long. But Kilauea pays no heed at all to anything that is happening two miles in the air above it and only twenty miles away. Evidently, then, the two volcanoes tap quite independent fiery lakes, and neither touches any molten core of earth.

It might indeed be, that the earth is liquid inside, but the crust so thick that there are within it all the local reservoirs that feed all the volcanoes of the world, some two hundred more or less active in the East Indies alone. But there come in the earthquake waves.

Italy, in the last thirty years, has had 13,500 earthquakes. Japan alone gets about four a day. Messina, Sicily, in four days of 1907 had eighty-seven. Somewhere the earth is quaking once an hour, nine thousand times a year. Each shock sends out a wave which may die out in a few score miles, or may be picked up by a station on the other side of the globe, by an instrument so delicate that it records the tilting of a five-story brick laboratory as the night-watchman goes his rounds, and a class of students, deep underground watching the seismograph, see the instrument record the advent of a late comer down the cellar stairs.

A dozen stations, then, pick up and record each tremor of the earth's crust, those near by getting the wave promptly by way of the crust itself; those farther away, partly through the crust and partly through the deeper portions; those still farther off, it may be, only the wave that has come by way of



SEISMOGRAM (somewhat schēmatic)

At P, appears the first warning of the earthquake, a back-and-forth vibration similar to a sound wave. This has come nearly straight through the earth. P′ is the same wave a few seconds later reflected off the earth's iron core. At S, arrives the transverse wave of the sort transmitted only by solids. S′ is its reflection. P (prima) and S (secunda) started together; but S travels faster. Thus the lag of S on P serves to measure the distance between the observing station and the focus of the earthquake. At L begins the long, main wave that has traveled around by way of the earth's crust. Later, the same wave may appear again, coming round the earth the other way. Occasionally, if the shock is very severe, the L wave may go round the earth twice in each direction, to give four records in all.

the earth's central mass, and a half-hour after the first shock. The record at each instrument is automatic, second by second; and each station can have copies of any record of all the rest.

The wave, moreover, is itself highly complex, partly a long-period sound wave, with a fore and aft movement that will travel through air or water

as well as through solid bodies, but partly various distortion waves that are carried by solids only. But the distortion wave comes straight through the earth's center. Therefore, is the earth solid all the way through.

Now the earthquake wave travels fastest in dense bodies—as is the way with all waves. Sound, for example, travels four times as fast through water as through air, and fifteen times as fast through iron. Therefore, by timing an earthquake wave at different points, one gets its velocity in different directions, and learns from that a good deal about the different sorts of material that it has come through. Moreover, we know by the way the earth swings the moon that it must average more than five times as dense as water. But the surface rocks are only about half that. So the interior must make up the difference. Clearly, then, the earth's center, so far from being liquid, is a great deal more solid than the part we know.

One thing with another, the most reasonable guess as to the earth's inside is that its center is an irregular iron core that is something like a sixth of the earth's mass and not far from half the earth's radius—a body, that is to say, just about the size of the planet Mars. There is no small reason for thinking that this is also just about the original

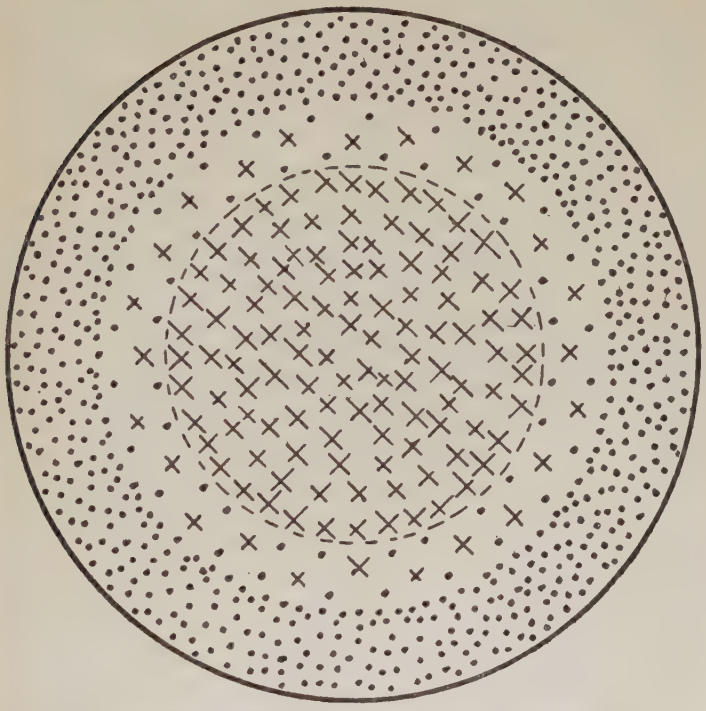
earth, which—it may be—the gravitation of some wandering star pulled away from the central sun that preceded the one that warms ourselves. So the earth may well have started on its own with half its present radius; and been built up slowly, during some hundred million years, as it has drawn in smaller heavenly bodies of various sizes down to the pin-head meteors, which it still acquires ten and twenty million a day and which we know as shooting stars. At any rate, the speed of earthquake waves, along with other evidence, suggests nearly solid iron for a rather strong two thousand miles out from the earth's center. In fact, the earthquake wave, coming in from the surface, actually echoes off this iron ball.

The next rather scant thousand miles from the center out suggests heavy rocks, mostly iron still, with more and more of other and lighter stuff along with it. The last thousand gets more and more like the surface rocks, with less and less iron and more and more silicon and the like. The last forty miles at the surface is the part we know directly, that is—just what we all see it. But, of course, there is nothing hard and fast about the limits of these shells.

Still, there is such a thing as liquid rock, even though the earth is on the whole twice as solid all

the way through as it is on the outside. Naturally, one wants to know where the lavas come from.

The surface rocks are hard. In fact, some of



PROBABLE CONDITIONS OF THE EARTH'S INTERIOR

The center is largely iron; the shell, compounds of silicon related to granite and basalt. Between the two is a transition zone where one element gradually supplants the other.

them are about the hardest things there are, except steel files; and both in human edifices and in natural masses, they stand up under enormous loads.

Moreover, the surface rocks that we see are almost everywhere full of open cracks.

But even granite will not stand up under infinite loads. So there must be a zone—it is at least some six miles down from the surface—below which all the rocks crush under the weight above them, there are no cracks or cavities of any sort, not even the smallest pores.

That region must also be hot. The temperature in deep mines increases on the average one degree for fifty or sixty feet; but some grow hot three times as fast. This, however, is only for the first mile. If the rate holds—as it pretty certainly does not very far—six miles down, at the bottom of the so-called "zone of fracture," the temperatures should be getting up toward a thousand Fahrenheit degrees.

Lava is not always especially hot. It will overflow a village and not melt up the church bells. Uncommonly hot lava, right in a seething crater, will melt silver and copper—at about two thousand degrees. But the melting point of ordinary cast iron is higher still; and long before the days of electric furnaces and high-temperature research, in fact, way back in Hutton's time, Sir James Hall—not he of New York—melted up Vesuvian lavas experimentally. So the heat is really taken care of.

What probably happens is that there is a somewhat vague zone somewhere around ten miles or more down in the earth's crust, where some of the more fusible rocks are just hanging between solid and liquid. A little change of pressure as the earth strains, some chemical action that produces heat, the friction as the rocks move as they are known to do, perhaps some cause yet unguessed, alters conditions just enough to let various cubic miles of the earth's mass go soft locally—and out the lava comes.

Apparently, then, underneath the "zone of fracture," there is a "zone of flowage," where all the rocks are mashed into the smallest space, and though they are for the most part solid enough to carry the earthquake wave, they do liquify locally and stay melted; and in general, instead of cracking and sliding as they do higher up, they are near enough soft to be squeezed along like pitch or putty under the enormous stress of the load above them. At something like forty miles down or less, all conditions work so far the same way as to make the solid earth act almost as if it were not solid. But all this comes by inference, and it may all be quite wrong.

If it be not wrong but right, some curious things result.

We are all supposed to know that it is the earth's gravity that keeps the pendulum of any clock swinging back and forth till the spring runs down and friction brings it to rest. Naturally, then—as is the fact—the greater the earth's gravity, the faster the pendulum swings. Men, therefore, measure very minute local differences in the earth's pull by taking pendulums here and there and seeing them slow down where the rocks are light in spots and speed up where the rocks are locally heavy.

A good many years of this highly accurate work, and there transpires a most remarkable fact: The continents of the world are lighter than the sea-floors. In other words, and a little more precisely, a block of the earth's substance from the floor of the deep Pacific down to the earth's center is nearly ten miles shorter than a similar block taken out of the Roof of the World in southern Asia. But the two weigh the same. The ocean basins are under the sea because the rock under them is heavy and has sunk down. The continents are up in the air because their rocks are light. This is the principle of isostasy, the notion that all parts of the earth are nearly in hydrostatic equilibrium, so that if a mountain were removed and cast into the sea, the sea-floor would sink just enough to ab-

sorb the extra load, and the land where the mountain was would come up just enough to balance, and somewhere down in the zone of flowage there would be a slow creep of the rocks away from the sea and toward the shore.

It follows, then, that the great ocean basins have always been sea, and the great continents have always been land. This was, indeed known before from other evidence—there are, for example, no stratified rocks on land to correspond to the vast areas of ooze and red clay of the deep sea. There has been a deal of seesawing up and down between flat land and shallow water. But the main ocean beyond the continental shelf has never seen the light of day. This takes care of all Flood Theories of a type held among others by Cuvier and still in vogue outside the limits of science, that make sea and land reverse at the Deluge, and our familiar stratified rocks be sea-floors laid down during the less than two thousand years between Adam and Noah. Dry land does, indeed, sink down to become shallow sea, "in soundings" as the sailors say; and floors of shallow seas do come up to make dry land. But sea-bottom a mile down stays there. All present-day evidence goes to show that deep sea and high land do not reverse.

One may then, conveniently, think of the conti-

nents as thin sheets of relatively light rocks—granites largely and their weathered fragments—that float on heavier basalts as ice floats on water. North America, then, three thousand miles wide and perhaps some thirty miles thick, is like an ice-floe a foot through and a hundred feet across. The problem is: Are North America and the other continents anchored or adrift?

CHAPTER X

CONTINENTS ADRIFT

THE continents, then, are light stuff, apparently afloat literally on a sea of glass.

The top of each continent is of granite or of granite derivatives—sandstones, shales, and the like—or else limestones and marbles that are about as light. That much, anybody can see. The bottoms of the land-masses are most probably of somewhat heavier crystallized basalt, frozen on to the under-side of the granite, the same sort of thing that comes out melted as volcanic lava. The continent seems to be altogether about forty miles thick at most. We can not be sure that it is more than about twenty.

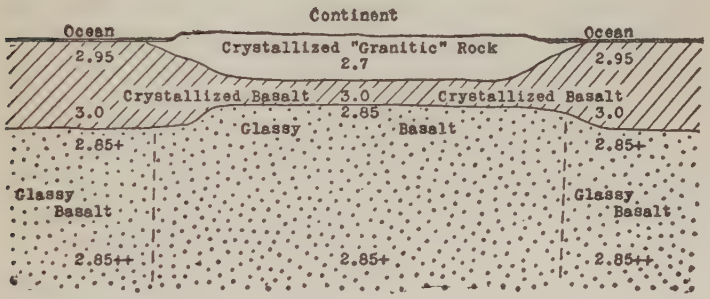
But the sea-floor, so far as is known, has no granite. All the thousands of volcanic islands, for example, that dot the Pacific basin, have not one cubic inch of visible granite in their combined mass. They are entirely basalt. Most of the land volcanoes also bring up basalt from the deep layers under them.

Under the crystallized basalt everywhere, beneath land and sea alike, there probably lies an uncrystallized basaltic glass, very hot, but kept solid by the enormous pressure of the forty-odd miles of rock over it. When this forty-mile crust cracks through, the pressure is locally relieved, and the hot glass melts locally, to flow out to the surface as a lava stream—if it does not freeze up on the way as sill or dike. The sea of glass that is under the earth is solid—twice as rigid as granite. But being a non-crystalline glass and not a mass of interlocking crystals, it will flow very slowly under great stress. Pitch and molasses candy have the same property. One can pull out molasses candy into long ropes—but one can also snip off the rope with scissors. All these "plastic solids," being non-crystalline, are rigid under quick stresses but yield to slow ones. So the glassy substratum of continental block and ocean floor transmits the earthquake wave almost like hard steel, and holds rigid against the twice-a-day tidal pull of the moon. But give it time—say a thousand years or two—under even a small steady force, and it runs like water.

One may, then, picture the upper fifty miles of the earth as very much like a pond which has frozen a foot thick, with logs floating in it that are less than a foot through. The logs were floating a little

out of the water. The ice formed; but their tops are still out. The ice is thick enough so that no log comes through into the unfrozen water; but the ice under the log is thin.

The log, then, is the granite continent. The ice is the crystallized basalt. The water is the uncrystallized basaltic glass. There is some reason for thinking that the granite continents—which really



From *Our Mobile Earth*, by R. A. Daly. Courtesy of Charles Scribner's Sons.

THE LIGHTER GRANITIC ROCKS OF THE CONTINENTS AFLOAT ON THE HEAVIER BASALTS

do have a much higher melting-point than the basalts—formed first, when all the basalt was liquid or solid glass, and that the crystallized basalt froze later, and is, indeed, still forming out of the glassy stuff underneath the continents and the sea-floor. At any rate, ocean water and some miles of heavy basalt in the sea and under it, just match, weight for weight, a much thinner layer of basalt with

light granite rocks above it. If either were heavier than the other that one would sink into the glass beneath.

The continents, then, are thin. Even so small a continent as Australia, only two thousand miles across has about the proportions of a postage stamp. As for the larger masses, a full-page map of the world is not far from correct in three dimensions, for the thickness of the paper just about corresponds to the thickness of the real land down to the under-side of the continent.

The continent is, therefore, not anchored to anything. The question is: Does it float around? The continent is thin. The question is: Does it crack?

There is a good deal of reason for thinking that both these occur.

Contrast the Atlantic Ocean with the Pacific. There are marked and curious differences between the two, though these are a good deal obscured by our ordinary maps and are best to be looked for on a globe.

The Pacific is a round basin, a sort of gigantic pond; but the Atlantic is a sort of gigantic river that winds from the top of the earth to the bottom, always of about the same width.

In fact, if one went by the shape of the coast on

the two sides of the Atlantic, one might well say that South America has cracked off from Africa, the eastern extension of Brazil once occupying the Gulf of Guinea, the western end of the Sahara belonging in the Caribbean region, Greenland jammed up against the west coast of Norway, and Newfoundland one of the British Isles. If one could push the two Americas eastward and a little north, so that Greenland lay against Canada on one side and Norway on the other, with Newfoundland and the British Isles pushed into the North Sea, the fit would be surprising.

There really is not a little reason for thinking that the uniform width of the Atlantic and the remarkable fit between its two sides is something more than accident. There is a good deal of evidence to show that during most of geologic time, and up to what for a geologist is rather a recent date, North and South America actually were parts of Europe-Asia-Africa, but cracked loose and floated off.

There really is not any possible doubt that North America and Europe, South America and Africa, and Australia and South America, have in the past been connected, because the same land-animals and land-plants have appeared at about the same time all around the North Atlantic. The

horse, for example, originated in our own West. But horses appeared shortly afterward in Europe, and presumably they did not swim over. On the other hand, the elephants originated in northern Africa; but fossil elephants are found widely over North America, so that the Alaskan Indians still make carvings of old elephant ivory. Our modern plants appeared so nearly at the same time on both sides of the North Atlantic that it is not certainly known where they first arose. So there must either have been a long bridge, which is now broken apart, from Europe across to America by way of Iceland and Greenland, or else North America and Europe must have been one land-mass.

The coal points very much to the latter theory. Our Western coal is not of the Coal Period, but much younger. Rocks of the Coal Period in Africa contain no coal at all. But the coal of Pennsylvania, New England, and Nova Scotia is of the same age as that of the British Isles, France, Germany, and Spain, and is altogether very much like it. So it looks as if, when the coal was forming, all this was a single coal-field that has since cracked apart. Moreover, throughout these two coal districts, through the entire length of the Appalachian Mountains on our side of the ocean and in Scandinavia on the other, the mountain ridges run

northeast and southwest, as if they were all parts of the same system; and in various ways the rocks match surprisingly.

Still more striking is this fact. In our Appalachian Mountains and throughout the flatter country westward to beyond the Mississippi, the rocks are obviously an old sea-floor, made up of sands and gravels and muds and lime, now hardened into solid rock, but having still, here and there, layers that are full of fossil sea-shells, and sometimes even entire branching corals standing as they grew, but now miles inland in the cliffs.

But if one looks at a modern shore, one can not help noticing that the strip of beach with its boulders, gravels, and sand is always narrow. A little out to sea, rarely more than half a mile from land, the sea-bottom is fine mud that only weak currents can sweep along. Farther out, in the clear water, come lime oozes formed from the remains of animal shells. Sea-floors, then, are banded characteristically, beach against the shore, then finer and finer muds, then lime.

No different was it in ancient days. The beaches formed against the land where the breakers knock the rocks about, and have since hardened into pudding-stones and sandstones. Farther out come the slates, which were once mud; and still

farther offshore are the limestones that were once animal remains and still oftentimes are full of fossil sea-shells. So it is almost always possible in every old sea-floor to make out on which side the land lay. Oftentimes, when one can locate the actual beach, the long-departed shore can be mapped almost as accurately as if the water lapped it still.

Now, the strange thing about all these old sea-floors, from New York southward into Georgia and westward at least as far as the Mississippi, is that when this region was ocean, the land did not lie to the west of it, but toward the east and north. All this vast district of farms and cities was built up of the land-wash from a continent that lay where the North Atlantic now is.

It must have been a large continent, for the sand and gravel and mud which the rivers washed out to sea and the waves ground up on the shore have built up most of half a dozen big states, while in some places the deposits are a mile thick. It must, at times, have been mountainous, for there is a characteristic difference between the wash from a flat country, where the streams are sluggish and the soil has time to decay thoroughly before it reaches the sea, and the waste of a high country, where the rivers are swift and the broken rock is quickly swept away. But we know that there were

ancient mountains in Europe that were worn down nearly flat and then lifted again, only to wear down once more. We know also that certain of our American deposits came from a mountainous country, and some did not. All together, everything fits together nicely if we suppose that the "lost continent of Appalachia" that furnished the material for our American rocks was Europe and never lost at all.

For Europe, on the other hand, the location of the ancient strands points to a lost land on the northwest. The old rocks of Scotland, Scandinavia, and Finland are nothing like in area what a land would have to be to furnish the sediments that have made the younger stratified rocks of all the rest of Europe. Either, then, there was a lost land on the northwest or else the material came from Labrador, Greenland, and the islands of the American Arctic.

The match between Europe and North America, as if the two were really torn apart, extends to a great variety of details. The mountains of Nova Scotia and Newfoundland correspond in age and kind of rock and direction to those of the British Isles, as if a single chain had broken apart. The very ancient rocks of the Scottish Highlands are identical with the equally old rocks of Labrador. The famous Old Red Sandstone of England

just matches the Old Red Sandstone of Nova Scotia. Even the dinosaur tracks in the mud of Triassic estuaries and river bottoms are alike across the sea—the vales of middle England on one side the water, the valley of the Connecticut River in central Massachusetts on the other.

In like manner, South Africa matches Argentina, bit by bit. Each had a glacial period at the end of the Paleozoic, similar to the recent one over North America and Europe. There are east-and-west mountain ridges in the Cape Town region in South Africa, concave in direction toward the north. And there are east-and-west mountain ridges, curving round toward the north, in Argentina, in the same latitude and of the same age. There are camels in Africa and llamas in South America. Of those strange missing links, the lung fishes, that are neither true fishes nor proper amphibians, there are only three species left—one in South America, one in Africa, and the third in Australia. But African and South American forms are more like one another than either is like the Australian.

Between the North Atlantic and the South, on the two shores, are the generally east-and-west Alps of Europe and the Atlas of North Africa, each trending equatorward on the west. Across

From *Our Mobile Earth*, by R. A. Daly. Courtesy of Charles Scribner's Sons.

Mountain Systems of the Americas and Western Europe

P. American portion of the circum-Pacific group.

I. Appalachian system and the old mountains of central and northern Europe.

II. Mountains of Argentina and South Africa.

III. Young and lofty mountains of southern Europe, northern Africa, and western and southern Asia, with the West Indies and the highlands of Venezuela and Guiana.

the Middle Atlantic, but somewhat farther south, are the east-and-west ranges of Guiana and Venezuela—and the two are the same age. South of each comes a flat country, desert in one continent, jungle in the other.

Moreover, there is a long, winding ridge at just about the middle of the Atlantic, from close up to Greenland well down to Antarctica. Ascension Island is on that ridge, with St. Helena, and sundry other volcanic isles. These volcanoes erupt non-basaltic, continental lavas as if they were land volcanoes, not volcanic islands in a wide sea. It may well be that that long mid-Atlantic ridge is the place from which the two great land-masses tore apart.

Apparently, then, up to the end of the Paleozoic, there was only a single continent, no Atlantic Ocean, and no Arctic. After the great coal period—the coal being alike on the two sides of the water, as if in a single district—the original single land-mass seems to have split apart on a line from Bering Strait, across the North Pole, between Greenland and Spitzbergen for the main crack, Iceland going with the west side, and then down through the Atlantic. Opposite what is now the last tip of South America, the crack turned eastward around South Africa, and then northward,

to cut off Australia from southern Asia and form the Indian Ocean, and to separate Antarctica from both. But Antarctica almost joins South America on one side, even now; while Antarctica and Australia seem to have hung together well up through the Age of Mammals. But, naturally, the cracks branched and reunited, and were altogether vastly more complicated than this simple account of them. For one thing, the floating blocks themselves seem somewhat to have changed shape.

The movement must have been very slow—in fact, it is probably still going on, with nobody noticing it. At any rate, there are now under way especially careful determinations of longitude for Europe and North America, and if there is any drift of either, in a century or two it should become evident.

Supposing there really is this continental drift, the date at which various land-masses broke loose from one another can be ascertained by the likeness or unlikeness of the animals and plants on two sides of salt water.

There are, for example, the higher plants, which one might as well learn to call "Angiosperms," the group which includes most vegetables that people are interested in from the oaks of the forest to the grass of the field but does not include the pines,

junipers, and the like. These appeared in great abundance and at the same time in both Europe and North America. Clearly, then, Europe and North America were still in contact in the Cretaceous, when the broad-leaved plants first appear. But the South American monkeys are quite unlike those of Africa. The latter, among other items, always have two premolar teeth just as we do, where the former have three, and the African monkeys never swing by their tails. In fact, the African monkeys are very much of our branch of the family. So Africa and South America must have split apart before the Miocene when the apes and monkeys especially flourished.

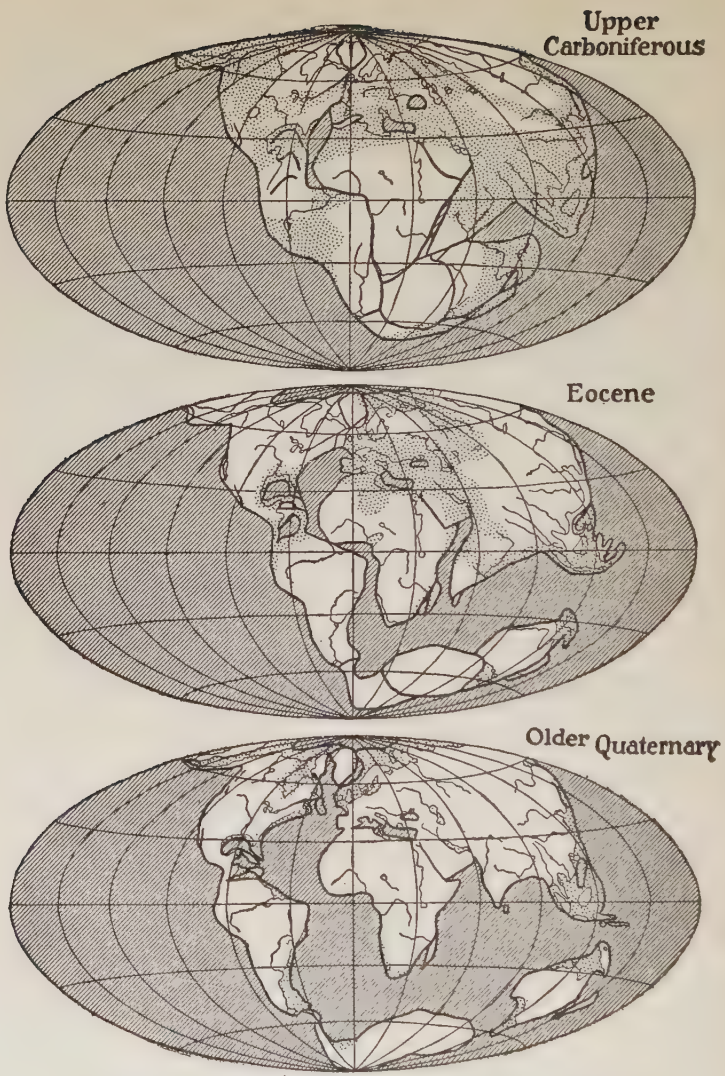
A vast amount of detailed evidence of this general nature, together with other evidence of a more strictly geologic sort, makes it highly probable that the primitive continent began to slip southward and to open up the Arctic Ocean as early as the late Paleozoic. At about the same period, Australia and Antarctica seem also to have been drifting south and beginning to open the east side of the Indian Ocean. By the Eocene, apparently, the two last had swung clear of everything except the tip of South America; the North and South Atlantic Basins were opening, but Africa still connected lightly with South Amer-

ica. The Scandinavia-Greenland-Labrador bridge lasted into the Human Period. Asia and North America still connect by way of Bering Sea.

In short, as now appears, the Eastern and Western Continents, since the beginning of Mesozoic time have been separating from one another across a widening Atlantic, while at the same time both are drifting somewhat less rapidly south. Meanwhile, the Eastern Continent has itself split, Australia has worked well south, and Antarctica slid clear over the South Pole. Captain Scott, it will be recalled, coming back from finding the Pole, was lost, in part, because he tried to drag too great a load of fossils. These were temperate-latitude remains, reliques of a time long before Antarctica had made its present southing and was still in a region of decent climates.

But why the continents should move is another question. Apparently they actually slide downhill. How they ever climbed up is still another problem.

In any case the Pacific seems to have been closing up from both sides, and to be narrower than it was by the whole width of the Atlantic. As for the Pacific and where it came from, there have been those who maintain that Earth and Moon were once one body and that the great, round Pacific



From Wegener's *Origin of Continents and Oceans*, with the permission of Methuen & Co., Ltd., London.

WEGENER'S THEORY OF FLOATING CONTINENTS; THREE STAGES

basin, so obviously different from the narrow and winding Atlantic, is the hollow left where the Moon came off. If that ever happened, it was all a very long time before the Paleozoic Age began, and present company had much better be getting back to things that it can see with its own eyes everywhere.

CHAPTER XI

FAULTS, EARTHQUAKES, AND RIFT VALLEYS

There are diverse causes of earthquakes—street-cars, for example. In city laboratories, near busy thoroughfares, the fine measuring has to be done at night, so that the instruments will stay still long enough to be read. I have myself, looking through a four-inch telescope on a tripod on my front lawn, seen a star image start up a crazy dance every time a trolley car ran violently down a steep place a furlong off. Shaking the earth is easily managed; and the earthquake wave will run through hard rocks faster and farther than a sound wave through the air.

But the chief cause of noticeable earthquakes is the slipping of the rocks along a crack. "The whole creation groaneth and travaileth in pain," and the old earth is always twisting and pulling and pushing, accumulating strains slowly, until the rocks can not stand it any longer and break. One gets the same thing with a frozen pond on a cold night. The ice cools and shrinks, its own elasticity taking

up the strain for an hour or two. Then the pull passes the elastic limit, and a long crack shoots instantly a hundred yards. Frozen earth acts the same way: there are always more little earthquakes in the winter.

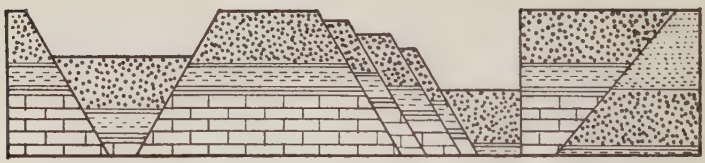
One sees these strain-cracks in most hard rocks—the "joints" as they are usually called. They most often come in three sets, more or less at right angles, two nearly vertical, one about horizontal. Sometimes there is still a fourth, set on a slant; and they will be a foot to a yard apart or more. Among them, the three or four sets of parallel joint cracks will take up any possible movement of the rocks by letting one block slip along an inch or two or a yard or two against its neighbor.

These slippings also go by fits and starts. The strain accumulates. The rocks slip. The slipping makes an earthquake. By and by, the strain accumulates again. Then there is another slip and another earthquake. So a district where the rocks are being strained gets a bad reputation, to which it commonly lives up.

One can often pick out the particular joint where slipping has been going on. The rocks that come together at the joint are commonly in contact and usually under pressure. When they slide, they also grind; and one can see the "slickensided" rock

surface peculiarly smoothed and polished as one block ground across the other. Usually, by running one's hand back and forth, one can feel the difference between going with and against the original movement, like the difference in a cat's back stroked the right way and the wrong. Each "slickenside" is then a sort of fossil earthquake. All old hard rocks have them, sometimes every few yards.

This same slipping of one rock along another shows also by the displacement of any sort of band-



STEP AND GRABEN FAULTS

From left to right: graben, horst, three step-faults, vertical fault, reversed fault. All except the two last are caused by rocks pulling apart. A reversed fault results from side-to-side compression, shortening the horizontal distance.

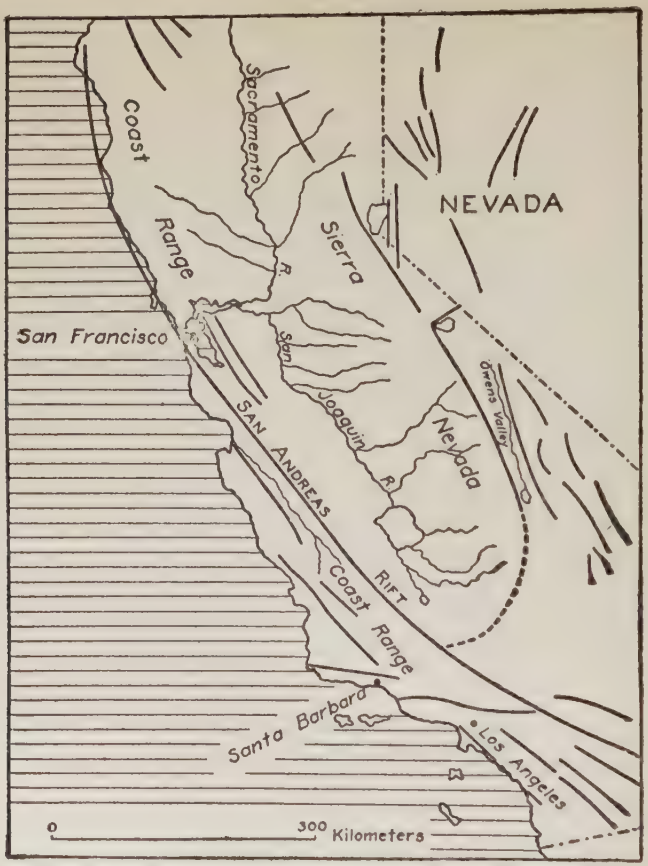
ing in the rocks. A little dike, an inch wide, may run up to a crack and be offset half its width, or several times that distance, or many feet. "Faults" is the name the miners give these offsets; and very bothersome they are, for if one cuts a coal seam or a mineral vein, there is good money gone, and the miner must hunt up or down or sidewise, to

find which way and how far the slipping has taken place to know where to dig for his lost deposit. It is no small part of the duties of a mining engineer to know the prevailing faults of his district, by way of guessing promptly what has become of a lost mine.

Such faults are of all sizes. One gets them in hand specimens—thin-bedded sandstones where the strata are no thicker than the covers of a book, and the throw of the fault is no more than the distance between printed lines, as if one tore through a page and slipped one side a few millimeters up or down. One sees gravel banks that have cracked when they were frozen, with a half-dozen faults in an area no larger than the side of a house, and no displacement greater than a few inches. But the California earthquakes of 1872 and 1906 each involved slips up to twenty feet.

On the other hand, in big mountains, there are cracks that run across country for a hundred miles, with one side upthrown a thousand feet. But these have taken geologic ages, a yard or two at a time.

A most remarkable type of fault is one in which the crack comes up from below at a rather low angle, say twenty or thirty degrees with the horizon, and bends as it rises, until near the surface the fault plane may be almost or quite parallel with



From *Our Mobile Earth*, by R. A. Daly. Courtesy of Charles Scribner's Sons.

SOME OF THE MAIN FAULTS OF CALIFORNIA

the strata. The rocks, therefore, do not lift, but telescope; and in a mountain district, where there is nearly always great compression, the upper side of the ancient crack will often have crept up, foot

by foot, over the lower, almost exactly as the frozen surface of a pond will creep up on a flat beach. But while the ice overrides the shore in a week or two, the larger "overthrusts" of the world must have taken many thousand years.

Such great "thrust faults" have been reported for a century, and from all over the world. Geikie found many in the Scotch Highlands where the rocks have telescoped miles. There is an especially

OVERTHRUST

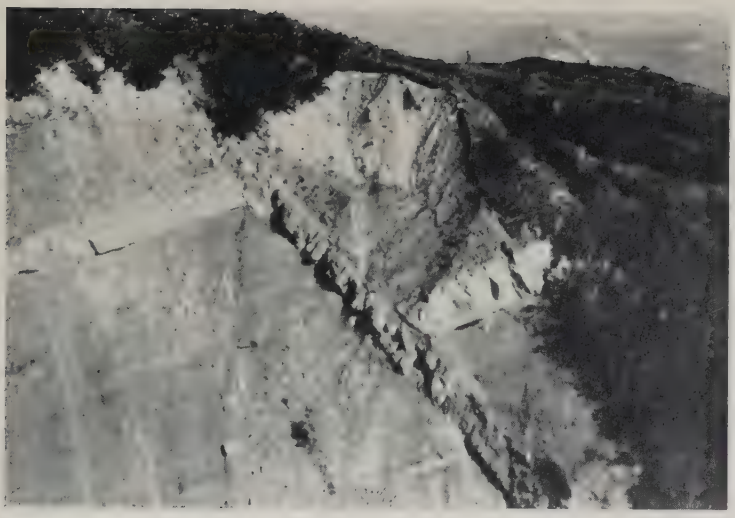
A nearly horizontal reversed fault has slid older rocks above younger. The strata, bending before they tear, show a "drag dip" next the fault plane.

famous one in Montana, close up to the Canadian line, reported by the United States Geological Survey, where during the upheaval of the Rocky Mountains, thick beds of limestone first buckled, then tore across, and then slid along nearly horizontally across much younger shales until the telescoping has now amounted to at least eight miles, with the nearly level slickenside "polished almost like a mirror." Another that runs across

country two hundred and seventy miles from Utah into Idaho has slipped a district twelve miles sidewise. The Appalachians show the same thing. In Virginia and Georgia no fewer than fifteen of these thrust faults lie northeast and southwest and parallel to one another, one of which, with an overlap of eleven miles, has been traced through the mountains for nearly four hundred.

It seems a great marvel that a layer of rock a thousand feet thick should be pushed up a slope, and along with the lift be carried horizontally ten or even fifteen miles. But one must not forget the scale on which nature works. Twice ten miles is less than the tenth of one per cent. of the circumference of the earth; and the ten-mile overthrust is only like the ice of a hundred-foot pool pushed an inch up the beach. The rattle of the windows in an old house is many times greater in proportion to its size.

Big or little, however, there is no question about the fact. Most mountain country is cut through by vertical dikes, each of its special width, each with its characteristic lava, and all spaced characteristically among their fellows. This is especially true of the Scottish Highlands where Geikie did some of the earliest careful work on horizontal faults. Geikie would pick out a dike in a hillside, and run it up to the place where the fault plane



Fault and Dike

Photograph by the United States Geological Survey

Step Faults Produced by a Single Earthquake

Nunatak Fiord, Alaska

Photograph by Lawrence Martin

cut it off. Then he found the same dike in another crag, cut off on the bottom by the same fault. That proved just how far the two ends have slipped apart.

In fact, the method is precisely the same which the miner uses looking for his lost coal seam. Only the coal bed, lying about horizontal, has been cracked up and down, and one end thrown up; while the dike, standing nearly up and down has been cut by a nearly horizontal crack and one end pushed sidewise. But the earth will push ten and twenty times as far as it will lift straight up.

Inevitably, when a block of country is made thus to override another, an older formation, that first lay underneath, is brought on top, to overlie a younger. So the strata are locally upside down. But this occurs only in a narrow strip, fifteen miles at most, and never outside mountain regions. Everywhere outside the faulted district, all those same formations will lie in their normal order.

These compression faults that shorten the distance round the world are by no means the only or even the commoner sort. More often by far, the rocks, instead of telescoping along the joints, pull apart.

What often happens is that two joints—or oftener, perhaps, two sets of joints—are formed with

the cracks standing nearly up and down, but tilted away from each other. So the block between has a V shape, apex down. Therefore, when the blocks pull apart, the V drops down, to make what is called a "graben" fault—from the German verb for "dig" and "sink," cognate with our own "grave" and "grub." This "graben" is a miners' term, reminiscent, like many another, of Werner and the Erzgebirge. Correspondingly, therefore, a similar up-thrown block is called a "horst." Present-day opinion has it the continents of earth are gigantic horsts; the ocean basins still more gigantic graben.

One sees such V's in sandstones, the dropped wedges the size of one's hand. A big earthquake will leave "graves" the width of a street with the drop waist-deep, or even sometimes the length of a short cross-street with the side walls house-high.

Still larger graben faults carry rivers and become "rift valleys."

The most famous of these is the Dead Sea-Jordan district. The mountains of Moab east of the river form a fairly level rolling upland, two thousand feet and more above the Mediterranean, built of stratified rocks, mostly limestone, generally about horizontal, of Mesozoic age, with a good deal of Tertiary lava that was intruded later and now

forms sills and dikes between and through the older beds. The whole district is volcanic.

The same Moabitish upland appears on the other side of the fault-block in the mountains which are round about Jerusalem, and the long ridge that runs north, a somewhat rougher country at about the same level, though the land rises toward the west. In short, here is a typical upland, with rolling hills, and steep slopes only where the high country drops off into the low. The White Mountains and the Catskills, or the district of the upper Ohio, let us say, from Pittsburgh down beyond Cincinnati, have essentially the same sort of topography.

The Jordan fault-block is ten miles wide, and "step faulted" at the sides. That is to say,—as commonly happens with a large fault,—the slipping has not been all done on a single joint, but on a series of parallel joints, each of a dozen doing its share. The result is a tendency to form terraces along the valley sides.

The surface of the Dead Sea is thirteen hundred feet below that of the Mediterranean. But the Dead Sea is itself, in places, another thirteen hundred feet deep. Altogether, from the top of the upland to the bottom of the valley, the drop is nearly or quite five thousand feet. But the upland

has been wearing down since the valley formed, and the valley has been filling up. Something like a mile at the least, then, has the ten-mile fault-block dropped down into the earth.

Northward the rift narrows, and the throw of the fault becomes less, for the fault is petering out. It forks, as graben faults often do, just south of the Sea of Galilee and sends a branch eastward toward Damascus. This also carries a large river, that comes down from the Hills of Bashan on the east.

RIFT VALLEY OF THE JORDAN AND DEAD SEA

The main valley is a graben, step-faulted at the sides. On the left, the central ridge of Palestine; on the right, the Land of Moab. Between the graben and the central ridge, another fault-block forms the Wilderness of Judea.

But the Jordan fault is itself only the fag-end of a greater rift that comes up from the south, the eastern branch of a wider graben that cuts across the Wilderness of Zin, and where it is below sea-level, forms the Gulf of Akabah. The western fork of the same graben is the Gulf of Suez and the low country northward where runs the Suez Canal.

The main rift is now the Red Sea. This forks eastward to hold the Gulf of Aden; then passes

across Abyssinia high in the air; holds those long, twisting lakes of east Africa south of the equator; and finally dies out in the Zambezi district behind Madagascar. Two hundred miles wide is that rift, in spots; and more than three thousand miles long. Nobody knows how great is the throw of the greater faults—but Arabia and Abyssinia near the sea stand more than a mile above it, and the Red Sea is a mile deep.

Such is the scale on which Nature throws her thrust and graben faults. Her mountain systems dwarf even these enormities.

CHAPTER XII

THE MAKING OF MOUNTAINS

The Ancient World did not like mountains. They obstructed travel. They harbored robbers and wild beasts. If they conveniently protected one's own country against invasion, they rather more than made it up by hindering one's own assaults on other people's flocks and cities. All our present-day attitude toward a high country—our sentiments of grandeur and beauty, our zeal for climbing everything in sight, is only one and a half centuries old. Mountaineering as a sport was the invention, or discovery, of De Saussure, who, being Professor of Philosophy at Geneva, climbed in the Chamonix and Monte Rosa districts, and in 1787, as has already been noted, was the first of mankind to reach the summit of Mont Blanc. His accounts of the glories of the high Alps started the fashion.

So the Ancient World kept away from the high country, getting ample exercise between battles out

of practising for war; and all mountain districts remained unexplored. The Great Gods dwelt on cloud-capped Olympus—which is less than ten thousand feet high, a hundred and fifty miles from Athens, and only ten miles from the ocean. But no Greek climbed up to see. Sinai is not even so high as Olympus—and the Children of Israel were camping right under its main peak!

The Middle Ages, early and late, liked the mountains even less than did the Ancient World, peopling them in imagination with gnomes and kobolds, giving them over to unholy Sabbaths of demons and witches. Safety and comfort—so far as men had either in prescientific times—were in the low country and the open valleys. Shepherds ventured into the upland and the high vales. There was some mining in the lower ridges. But, in general, up to less than two centuries ago, men kept to the grass-land and the forests and did not venture on to bare rocks. The mountain districts, in any detail, were virtually unknown.

But there are certain aspects of earth-science that can be made out only in a mountain country. So long, then, as geology remained a lowland science, there were closed chapters in earth's history, there were problems of earth-structure to which there was no answer.

Of these, the origin of the mountains themselves was inevitably one. Men noticed the lower peaks and the foot-hills, and made them out to be, for the most part, stratified rocks, of the same sort as the familiar lowland. But the mountain strata are characteristically bent and broken and knocked about, as those of the low country seldom are. So there was a fact to be explained. But nobody sifted out the facts in any sort of detail.

It was easy, therefore, to fall back on the all-prevalent theology. All the stratified rocks are, vaguely, the original crust. "And God said, Let the waters under the heaven be gathered together unto one place, and let the dry land appear: and it was so." Getting the dry land up would naturally crack the rocks. The mountain structure is accounted for.

Or if one's theology did not permit any imperfection in the created universe previous to Adam's fall, then one turned instead to the Flood story. "In the six hundredth year of Noah's life, in the second month, on the seventeenth day of the month, the same day were all the fountains of the great deep broken up . . ." The jointed and faulted and twisted strata remain, to prove the story of that dreadful time when, all at once, the entire crust of earth smashed to bits at the divine command,

and whole continents sank down into the waters that are under the earth.

To be sure, the actual story of the Great Deluge as Genesis sets it forth, distinctly implies a rather quiet flood. The water rose "fifteen cubits" in forty days. That is less than a half-inch an hour. A river flood in a spring freshet often comes up as fast as that. The daily tide comes in some ten times as rapidly. All the water of the Great Deluge is accounted for by a fair thunderstorm that kept going day and night for the forty days; while the breaking up of the fountains of the Great Deep probably means no more than a moderate opening up, until they delivered two or three times their normal flow, of the outlets of the hillside springs and especially of the fairly large underground rivers that are characteristic of nearly all limestone countries. The whole account is of quiet, slowly-rising waters that "bare up the ark, and it was lift up above the earth."

If it be objected that the flood water had to stand over the top of Ararat, the reply is obvious. There is no suggestion anywhere in the Biblical narrative that the surface of the flood was level. A miraculous deluge that "suspends natural law" may just as easily veneer the country fifteen cubits deep everywhere with no more depth over the

Mesopotamian delta than over the peak of Ararat, following the contours of hill and valley like a blanket of snow. Something just about like this seems to be pictured in the narrator's mind. One must not forget that it was not until well into the eighteenth Christian century that men finally learned enough physics to make them sure that water stands level and does not run up-hill.

However, the few persons who, before the end of the seventeenth century, bothered their heads over the structure of mountains and their origin, for the most part dismissed the whole problem as covered either by the ninth verse of the initial chapter of Genesis, or by the eleventh verse of the seventh chapter, or still more vaguely by "a fallen and ruined world" and "the wrath of God against human sin." Anybody who wanted to imagine earthquakes of any violence or water waves of any size, just went ahead and did it. The practise, alas, still prevails where science and theology continue to be mixed.

The first man who really set himself seriously to work to unravel the problem of mountain-building was Peter Simon Pallas of Berlin; for the Germans, because they have one of the world's ancient and important mining districts, have ever, from the beginning of modern geology, led the science on that side.

Catherine the Great spent the last half of the eighteenth century trying to civilize Russia after the manner of Peter, her still greater relative; and along with other civilizing influences, she first brought Pallas to St. Petersburg, to the chair of Natural History in the Imperial Academy, and then sent him off on a six-year exploration of the Ural and Altai Mountains, eastern Russia and Siberia, followed by another of two years to the Volga district, the Caspian Sea, and the Crimea. It was a hard life, in an almost unknown country. Pallas, among other things, had a hand in finding that famous extinct frozen elephant that for half a century figured as evidence for Noah's Flood—as it still does, though why anything in a river delta should go to prove water elsewhere, or why water in a river needs to be proved at all, are both quite beyond the scientific mind.

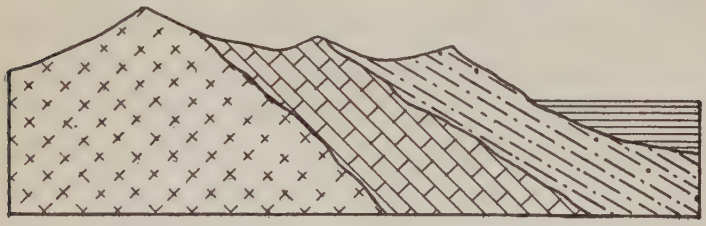
Pallas's *Consideration of the Structure of Mountain Chains,* which the St. Petersburg Academy brought out in 1777, really begins the systematic study of mountains. De Saussure applied Pallas's notions to the Alps, De Beaumont who was head of the French Geological Survey tried them out on the Pyrenees. In general, for the first half of the nineteenth century, Pallas's ideas were the prevailing doctrine.

Theories of this type emphasize especially the upthrust of the mountain system from beneath. The strata were, of course, originally horizontal, the stratified rocks lying, in general, over granites. The mountain range bows up in a long narrow arch. The rocks break. The tops of the blocks are worn away. There develop parallel ridges, granite in the center, old stratified rocks next it with their beds standing almost on end, younger rocks farther out that are less inclined, beyond the mountains the horizontal strata of the plains that are younger still. It is a straightforward notion, and it fits the general structure of most mountains.

Two other notions follow from the facts which support this. As it turns out, when mountain strata are carefully examined, they prove, in general, not to have been one single set of beds piled up one on top of another, the whole mass built up before any of it began to be uplifted from the sea. On the contrary, the relations of the strata prove that only certain of the lower layers were formed before the lift began. So the mountain starts to grow, and then stops. Horizontal strata are laid down, butting up against the mountain flanks "unconformably." Then comes another lift; with more horizontal, unconformable beds. The process may go on for geologic ages, and the uplift come by a

dozen separate elevations. The age of each can be made out from the fossils of the successive beds. If the last uplift was, for example, at the end of the Cretaceous, then the Cretaceous beds will be inclined, but the Tertiary beds will still lie horizontal.

So it is proved that mountains are not created in the beginning to survive unchanged. Neither



GRANITE MOUNTAIN FLANKED BY STRATIFIED ROCKS

Since the stratified beds must have been laid down about horizontal, their present attitudes prove at least two separate uplifts with quiet intervals before and after.

are they rocks of a prediluvian world formed all at once. On the contrary, each range has had its own history, and that history is highly complicated. Furthermore, all the high ranges of the world are new, the results for the most part of elevations long this side of the early Tertiary.

For the second notion, it now becomes clear that mountains have nearly always come up out of the sea. Their rocks are mostly sea deposits. Their flanks, when they were young, were buried in offshore muds. In spite of their granite cores—

which, indeed, are often quite wanting—most high ranges are built rather of weak stuff than strong, of stratified rocks rather than of massive.

As for the reasons why mountain ranges should be lifted up at all, and why here rather than there, there was little evidence yet made out and speculation ran riot.

Thus, for example, opines Amos Eaton, one of the most prominent, certainly the most profuse of American writers on geology of the eighteen twenties and thirties, author of two text-books, the teacher of several thousand pupils in the only school except Yale where geology was taught at all. ". . . the internal heat of the earth immediately beneath the granite, by converting the water which remained in the subterranean interstices into steam, began to raise up the blocks of granite. [Eaton, being a disciple of Werner, of course thought granite to be water-deposited.] The expansion of this steam found relief by forcing its way wherever the least resistence was presented, and as strata can be separated from each other easier than they can be broken through, the steam probably travelled laterally round the earth, separating the granite from the next stratum below. [This is, of course, the old "onion-coat" earth with its lower strata continuous over all the globe.]

At length the force of the more highly rarified steam became too great to be any longer confined within the coat of granite. It burst through the weaker part and shot forth its craggy broken edges above the muddy waters which surrounded it."

This in 1818; in the leading American text-book in its subject.

As to the source of the heat that generated this steam, Eaton suggested two possibilities. It might have been "excited by the concentric layers of metallic plates serving as a vast galvanic battery"—little was known then about electric currents; one imagined anything; and Eaton, on other grounds, believed in a primitive ocean of hydrochloric acid! Or more likely, as Eaton held in later works, vast beds of combustible material—presumably, in part, coal and sulphur—were conveniently located under each of the great chains of the world. Their burning blew up the central portions of each range and carried up with it the outlying beds. Fortunately, in these modern times, all this fuel is pretty well burned out, and only a volcano here and there reminds us of what things once were like.

Eaton had another curious idea, wide-spread in his time and still discoverable in out-of-the-way spots, that the present land-masses of the world are not the original ones. "When the wickedness of

men drew down the vengeance of the Almighty," and the fountains of the great deep were broken up, the earth that Adam tilled in the sweat of his brow and Noah walked in his youth, sank down beneath the waters never to rise again; and is now, presumably, the bottom of the Indian Ocean. At the same time, an old ocean floor came up, and is now Asia, Africa, and the Americas. So there are stratified rocks on the present continents that were not laid down by Noah's Deluge, but belong to the period, 1656 years in length, between the Creation and the onset of the Flood. Thus does early American geology sidestep the difficulty of getting all the stratified rocks into the Flood year.

"At any rate," writes Eaton, a few years after Waterloo, with Napoleon safely tucked away on the lavas of the mid-Atlantic ridge and Victoria only a few years short of being born, "the fountains of the great deep were broken up, and our continents, then at the bottom of the great deep, emerged into open day, scales of various thickness from the various strata were shot up, detached, and broken, which gave formation to our surrounding hills, the ragged cliffs of the Catskill and the bleak brow of the Andes. Some were formed at the bottom of the sea by volcanic fires; others have arisen from various causes since the great deep retired."

Eaton, in short, like most men of his day, has come to see that mountain ranges are no part of the original creation. Eaton besides, also like most men of his day, does not need any urging toward "the scientific use of the imagination!"

CHAPTER XIII

FAULTS AND FOLDS

In the end, however, as mountains came to be more thoroughly studied, it turned out that the uplift of mountain systems from underneath is not their most significant feature. The important point is that all the great ranges of the world, and most of the small ones as well, have been compressed from side to side.

One sees this on a small scale even in hand-specimens. Even beach pebbles, for example, in a thin-bedded gneiss, will show strata the thickness of cardboard wrinkled into tiny folds less than an inch across, with equally tiny faults, the tear an inch long and the "throw" of the fault where the torn layers have slipped, no more than the diameter of a pin. Clearly, the layers have been compressed from the sides; and the folds, if straightened out, would make the pebble twice as broad and half as thick as it is now. The whole thing is just a little mountain system, the size of one's hand.

One gets the same thing, in the right sort of

country, on a bigger scale in the ledges. Beds of limestone or shale, or the bands in a gneiss, may be an inch through or a hand's breadth. These thicker beds make larger folds, a foot across or waist-high as one stands to examine them. Again, the strata have been pushed together from the sides, the horizontal dimension shortened to something like a half, and there is the making of a little mountain range the size of a plowed field.

The foot-hills of a larger range often show the same sort of folds as high as a house, or as high as an office-building, with the strata ten feet through, but all in sight at once in a single cliff. Sometimes, where the gorges and the railway cuts lie conveniently across such a fold, one can follow the earth wave along its crest, see it lift out of the flat rocks, bow up gently at first, then more and more to its highest point, and then fade away into the plain, while another fold parallel to it, takes up the thrust. Often, within a hundred yards, one can make out a fold that has bent up till a stratum has been brought in contact with itself. Beyond this, the folding can not go, and the rock has to tear to an overthrust fault.

Still larger folds are too large to appear in any single cliff and thus to be seen all at once. These must be made out piece by piece by mapping. In a

big range like the Alps, some of the folds are thirty miles high—or would be if the strata could be restored where it has weathered off the tops. But the Alps never were thirty miles high, for the tops have been weathering off nearly as fast as the ridges have been lifted up.

So, as it turns out, the tilted strata on the mountain flanks that Pallas and De Beaumont inter-

Overthrown Fold

Folded strata are so much compressed that some of the folds have been carried beyond the perpendicular and older strata appear above younger. At the left, where the layers are overthrown, a reversed or false dip. Near the middle, a fold has torn to a reversed fault.

preted as horizontal beds uplifted from below, are really, for the most part, folded beds, compressed greatly from the sides, with the tops of the folds worn away. If one could put back the crests of the Alpine folds and straighten out the bends, the southern border of the Alps would lie somewhere down in Italy. If one could do the same thing with the Appalachians, Richmond would be over Norfolk, and Boston somewhere out at sea. The earth's crust, in a big mountain range, has slid one and two hundred miles over the glassy sea beneath.

The thrust that makes the mountain range comes from one side only, not from both—from the south for the Alps and Himalayas; from the southeast for the Appalachians. Thus in the Appalachians, the folds on the ocean side are greatly compressed, torn and overthrusted, or even overthrown so that their tops lie sidewise of their bottoms. But westward, the folds die down, first to moderate waves, then to gentle swells, and finally, as in the Cumberland Plateau, to a high country of horizontal rocks that have been elevated, indeed, but not folded at all. Beyond that, the strata continue nearly flat, till the strata of the high plains again fold in the foot-hills of the Rockies. For the Appalachians, therefore, the mountain-making thrust must have come in from that old lost continent that once lay east of North America—and possibly was Europe.

These "overthrown folds" of the eastern Appalachians were a sore puzzle to American geologists along in the eighteen twenties and thirties, when folds began to be especially noticed, and the strata in the great wilderness were first coming to be accurately mapped.

For evidently, when rocks are horizontal and undisturbed—as they mostly are—the older strata are always lowest down. But if the strata are

barrel-vaulted till the fold is about as high as wide, the older strata at the sides of the fold are forty-five degrees down and inward from the younger. If, however, the wrinkling has gone still farther, so that the fold is very much compressed and the strata are about vertical, then older beds that were underneath are now inside. Therefore, the top of the fold being worn away, the beds repeat as one travels across country, young to old, then old to young again—a, b, c, d, d, c, b, a. If the bending goes still farther so that the fold is actually overthrown, the beds on one side will have been carried past the vertical and made to dip the wrong way—an "inverted dip," as it used to be called. The fold will now look like a continuous series of strata—only the position of half of them will be wrong, with younger beds beneath the older.

The same puzzling arrangement comes about as the result of an overthrust fault, except that here the beds will repeat in the same order—a, b, c, d, then the fault, and again higher up, a, b, c, d, once more. Again, c and d, are both above and below a and b.

In a flattish country, heavily forested, before the days of railway cuttings, the old geologists, working hastily and with poor maps, were sometimes quite astray in their interpretations of their districts, especially where the strata alternated mo-

notonously, shales and limestones, all about alike and with few distinguishing fossils. The eastern border of New England, for example, next New York, and even some portions of the Alps, have been described quite inconsistently in different old reports, as if the whole thing were guessing and strata of any age might overlie one another in any order. Great play has lately been made in anti-scientific writings of what were unquestionably errors of interpretation of highly obscure facts.

All such, however, sooner or later, get straightened out. The railways are put through; quarries are opened up; somebody discovers a new fossil bed; somebody else happens upon an unsuspected fault. Gradually, ingenious hypothesis alters to virtual certainty, and another problem is solved. There is no reason to suppose that there will ever be an instance of strata apparently in the wrong order, where sufficient study will not bring to light the full proof of an overturned fold or a thrust fault.

But if virtually all the mountain ranges of earth arise by side-to-side compression of stratified rocks, with more or less in-squeezing of granites and basalts, and more or less out-squeezing of lavas, there still remains the problem: Whence came the squeeze?

Élie de Beaumont, among others, in a series of

books and essays between 1833 and 1852, argued convincingly for Leibnitz's old notion of a fluid globe.

According to theories of this type, the hot and molten earth froze rather quickly at the surface to a hard and coolish crust not altogether unlike the one we now know. But the inside remained liquid and very hot. The crust, then, is cold and rigid. It gains heat from below from the hot interior. It loses heat at its surface, radiating it away on cold nights till the dew falls or the frost forms. On the whole, the crust keeps at about the same temperature for long stretches of geologic time. But the interior is cooling steadily.

So the interior contracts, and the crust thickens as the solid rocks keep freezing down. Naturally, in the course of time, the interior gets too small to fit the crust. Naturally, also the crust has to fall down to keep contact. Therefore does the crust wrinkle to make itself small. The wrinkles are the mountain systems. Presumably, in the old days, when the crust was thin, mountain-making was rather easier than now.

Nothing could be simpler or more logical than this idea. It has always been a favorite theory ever since De Beaumont set it forth. It has abundant following still among persons who hold that the

world, whether originally melted or not, is cooler now than it was once. On the other hand, it may very well be that the earth is not cooling off, but warming up. But a warming earth should be forming open cracks and dikes and graben faults, not overthrust faults and mountain folds.

The whole matter is highly speculative. Just now the fashion is to regard the world as cooling off. Twenty years ago it was thought, on the whole, to have been warming up. Forty years ago, everybody was perfectly certain that it was once fluid. Really, all the while, it has been anybody's guess which it was.

But in any case, a cooling globe alone will not account for all the phenomena of mountain folds.

For one thing, there is the one-sided thrust, like that which came in from the southeast to overthrow the great folds on one flank of the Appalachians, but did not even wrinkle the strata on the other. A crust merely falling in on a core too small for it could hardly, one would think, give so markedly unsymmetrical bends, with so obvious a "shove side" as appears in all great mountain systems. Those sharp folds on one side gradually fading out on the other suggest rather the forty-mile-thick continent sliding down-hill and plowing up the sea-floor in front of it.

For another thing, there is the peculiar distribution of the high mountains of the world.

Of these there are two systems. One is a generally east-and-west band, though with plenty of local twists, that makes successively the Atlas and the Pyrenees, Alps, Carpathians, Caucasus, the highlands of Persia and Afghanistan, and the Roof of the World, turning thereafter somewhat south to become the Malay Peninsula and the East Indies. A patch also of this system appears in the Western World in Venezuela, Central America, and the West Indies. That great system certainly does suggest that the Eastern and Western Continents are both sliding away from the North Pole, opening up the Arctic Sea—which is unexpectedly deep—and wrinkling those stratified rocks halfway round the globe.

The other great system surrounds the Pacific. There are Graham Land and Antarctica, that connect by way of shoals and islands with Tierra del Fuego and the Andes. The Andes connect through Central America and Mexico with the Rockies, the Sierra Nevada, and the rest; and the same great system crossing over into Asia by way of the Aleutian Islands and Bering Strait, comes southward as several parallel ranges of which Kamchatka and the Japanese Islands with Formosa and

FOLDED LAYERS IN SCHIST

Pre-Cambrian of the Canadian Shield. Shipton, Quebec

Photograph by the Canadian Geological Survey

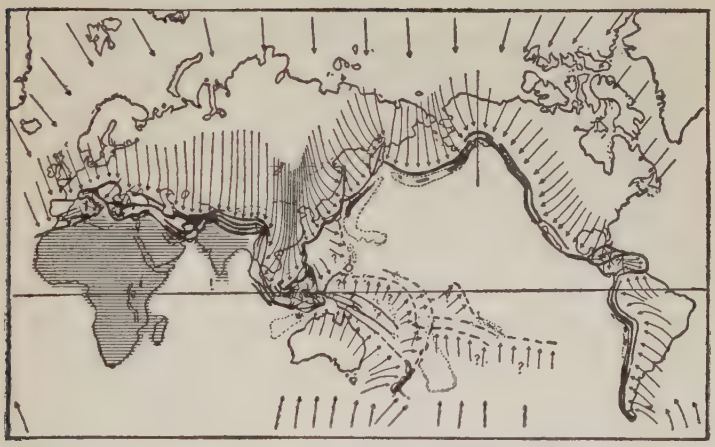
FOLDED STRATA OF MOUNTAIN DISTRICTS

Mount Heavens, Montana

Courtesy of *R. A. Daly, Department of Geology, Harvard University*

the Philippines are one. The great folds keep on through the East Indies and across Australia, finally to reach New Zealand. What there may be in the way of submerged mountains in the thousand-mile break from New Zealand to Antarctica remains still to be explored.

At any rate, there is a continuous band of mountains, sometimes on land, sometimes rising



From *Our Mobile Earth*, by R. A. Daly. Courtesy of Charles Scribner's Sons.

TAYLOR'S THEORY OF THE FORMATION OF MOUNTAIN SYSTEMS BY THE MIGRATION OF CONTINENTS

from the sea-floor, some thirty-five thousand miles long, that borders the Pacific. It all looks very much as if the Pacific Basin were a low spot on the earth; and all the land on earth were sliding down into it from all sides.

In short, of the newer and high mountains, there is a mid-latitude "Mediterranean Zone" and another "Circum-Pacific Zone." The two connect. Apparently they influence each other. On the whole, however, they are distinct, as if a migrating land area had two independent movements, one away from the North Pole, the other toward the mid-Pacific.

Besides these two, there are older mountains, like the Appalachians, that are now pretty well worn down to their roots, which do not belong to either zone.

The matter is really very complicated. For one thing, the spin of the earth—like that of all the planets and the Moon—has apparently been slowing down. So the day is getting longer—very slowly indeed now, possibly no more than one second in a hundred thousand years, though apparently much faster in the past. But if the earth once spun faster than now, then its equatorial bulge was correspondingly greater—a hundred miles perhaps, instead of the twenty-seven that it is now. As the spin slows down, the earth should find its equatorial belt too high in the air and its poles too near its center. So the continents should tend to float poleward as well as toward the Pacific. The two shoves combined might make the push

to the northwest that has made the very old Appalachian system.

But all this is too much in the air.

What seems to be happening on the earth is that most of the sand and mud that the rivers bring down to the sea, and most of the sand and mud and boulders that the sea itself knocks off its headlands and grinds up in its waves, finally works a little offshore and forms a zone of land-wash all round the borders of each continent—the so-called "continental shelf," that is in general fifty, a hundred, two hundred miles wide. The sea here is shallow—always less than about five hundred feet, often so shoal that men catch cod off the bottom with a hand-line a hundred miles offshore and a vessel sinks with its masts sticking out.

This "continental delta" keeps building up toward the surface, partly with the land-wash, partly also with the remains of corals and other sea things that grow on it. It does not, however, build up to the very surface. For the sea-floor also, is afloat on the layer of glassy basalt, and as the floor loads up with the land-wash, it keeps sinking down. Thus, offshore from a mountainous continent with large rivers, the strata on the continental delta have piled up sometimes fifty thousand feet in old continental shelves that are now dry land. Yet

here and there, throughout the fifty thousand feet, are coal beds, fossil shallow-water creatures, ripple-marks, footprints in dried mud. Evidently, the bottom sank about as fast as the top built up, the sea was never deep, and the bottom sometimes came up to the light of day and became dry land or swamp.

But as the continental delta piles up and sinks, its bottom tends to melt off, or at least to become part of the glassy mass below forty miles down. The result is a patch of rock, generally a long strip parallel with the shore, that is unlike the rest of the earth's crust. Instead of being old and hard and strong, it is new and soft and weak. When, therefore, the thrust comes and the crust must fold or break somewhere, the yielding comes in the off-shore strata. There are the wrinkles. There are the mountains formed.

Apparently, at the beginning, the new mountains do not rise up. The thrust is from the side. The strata buckle. But being heavy, they buckle down into the yielding glass below them, quite as much as they buckle upward against gravity into the air. Afterward, ages afterward indeed, as is proved by the age of the horizontal strata that occupy the troughs between the folds, for reasons that are still highly obscure, the whole district is

lifted up from below. That is why all high mountains rise out of high plateaus, and the unfolded strata on the sides of the range like Tibet and the Great Plains east of the Rocky Mountains, are themselves a mile or two in the air.

A new-formed mountain range is, therefore, more like the West Indies, or the East Indies, or the Aleutian Islands, or Japan, or New Zealand—mostly under water. Only after geologic time, does the district come up to become Alp or Himalaya. There are, then, two stages to making mountains. First comes the thrust from the side that folds the rocks, or telescopes them, hard layers across soft. Then comes the uplift from beneath that makes high continents out of islands and seafloor.

But mountains are always the children of the sea.

CHAPTER XIV

THE CARVING OF THE LANDSCAPE

JOHN MILTON, both following theologic tradition and sustaining it, will have it that mountains and valleys alike are parts of the original creation, established in the beginning, unaltered to the end. The famous Seventh Book of *Paradise Lost,* composition of the early sixteen sixties, proceeds thus, the Archangel Raphael narrating the creation to Adam:

". . . when God said,
'Be gather'd now, ye waters under heaven
Into one place, and let dry land appear!'
Immediately the mountains huge appear
Emergent, and their broad bare backs upheave
Into the clouds; their tops ascend the sky.
So high as heaved the tumid hills, so low
Down sunk a hollow bottom broad and deep,
Capacious bed of waters. Thither they
Hasted with glad precipitance, uprowled,
As drops on dust conglobing from the dry:
Part rise in crystal wall, or ridge direct,
For haste; such flight the great command impressed

On the swift floods. As armies at the call
Of trumpet . . .
If steep, with torrent rapture, if through plain,
Soft-ebbing; nor withstood them rock or hill;
But they, or underground, or circuit wide
With serpent error wandering, found their way,
. . . within those banks, where rivers now
Stream, and perpetual draw their humid train."

For Milton, in short, there was no geography in our modern sense. John Ray, in fact, a third of a century later, seems to have been about the first of mankind to see clearly that if all the rivers of earth are for ever washing down mud into the sea, that mud must come from somewhere. So the country from which the mud derives has to change shape. But for Milton, the landscape is fixed in an eternal state, unaltered from the Creation to the Day of Judgment.

This was, however, even in Milton's time, by no means universal opinion. There was always Noah's Flood, the one great agent in all geologic events. Men had, then, only to imagine powerful currents and vast waves, that swept to and fro over the drowned lands, scoured out the valleys, and left the landscape precisely as we see it now, barring an occasional beach or meadow. The Flood, therefore, accounted for all geology, and all geography as well. This opinion still obtains among persons

who have missed the modern grammar-school course.

To be sure, the Flood narrative gives no hint anywhere of waves or currents or any other sort of violence. All this is superposed on the Biblical account. But when have theologians ever distinguished between what the Scripture says and what they have themselves added to its meaning? So the Deluge of Noah rivals the original creation as the reason for the local landscape. But heathen opinion had it that Titans or Frost Giants had done battle and thrown the mountains about for missiles. So the valleys just happened, never either washed out or planned.

Yet, as one looks over an actual landscape, especially in a rough country,

> "It seems some mountain rent and riven,
> A channel for the stream has given,"

and the idea early takes shape that convulsions of nature, long since both the Creation and the Flood, have shaped the valleys and made the landscape.

There really are such valleys. The Jordan rift is one. The lower Connecticut, from northern Massachusetts down nearly to Long Island Sound was another in Triassic times; and the great dino-

saurs left their tracks and their bones in very much such a graben valley, for size and character, as is the Jordan Valley now.

Mostly, however, the walls of valleys are not faulted, and the valley has not been opened up by any sort of convulsion. On the contrary, stream valleys often cut right across great faults, paying no attention to them. Sometimes, indeed, a river running lengthwise of a fault that might have made its valley, swings back and forth across a crack as if there were nothing there.

There are also a few districts of the type of the great interior valley of California, where the Sierra Nevadas have risen up on one side and the Coast Ranges on the other, and left the central lowland between just about as the whole state was once. But that sort of valley is uncommon. In general, all valleys, carefully examined, prove to be nothing more than the places from which the rivers have washed away the rocks. All mountain peaks, therefore, are simply the places where the rocks still remain. The landscape, in short, is the work of the streams.

One gets really the best idea of the marvelous cutting power of a running stream by looking at the pot-holes in the bed of a mountain brook.

Not all brooks have them. But in general,

where a rapid flow comes down over bare rock, there will always be depressions in which pebbles will lodge. These pebbles, therefore, instead of being rolled along down-stream as pebbles commonly are, stay where they were, and grind round and round in the current, till they wear down to sand and mud and are washed away. Other pebbles, washing down from above, lodge in their turn. These, also in their turn, grind and grind and grind, year after year, till they grind out a hollow in the hardest rock. As the hollow deepens, it catches more pebbles, the hole grinds rounder and smoother, a better whirlpool forms in it, and the grinding proceeds still more efficiently.

The result is a smooth round pot-hole drilled into solid ledge. I have seen such pot-holes in a mountain brook, three and four feet across, drilled down into granite five and six feet, and as round and even as they could have been turned on a machine. The famous Giant Pot-Hole at Lost River, New Hampshire, that is thought to be the largest thing of its type on earth, is twenty-five feet in diameter and thirty-five feet from lip to bottom, in solid granite, with walls almost as smooth as the polished surface of a granite tomb-stone.

Mostly, these pot-holes come in sets, a score or two on one bare ledge of half an acre. More often

POT-HOLES

Stream gorge formed by a series of connected pot-holes. Cockermouth River, Groton, New Hampshire.

Photograph by the Currier Studio, Franklin, New Hampshire.

The Giant Pot-Hole at Lost River, New Hampshire.

Courtesy of the *Society for the Preservation of New Hampshire Forests.*

perhaps, they form a single line down the stream bed, one after another for a score or two of yards. In either case, they will be of all ages, from new ones just starting in the hollow from which the frost has broken out a fragment the size of a man's head up to the finished product in which a man can stand up to his neck. Rather often, the cavity enlarges below the lip to something not unlike a vase in outline, so that as the pot-hole grows it cuts through into its next neighbor. I have even seen a pot-hole so flask-shaped that its bottom part had been tapped from above by a tapering neighbor that drilled down into it.

Inevitably, as the pot-holes enlarge their diameters, the walls that separate them become thin in spots. There is a foot of solid rock between two neighbors, then six inches, then one inch, then a hole. By and by, these holes begin to carry a part of the current. Finally, the line of connected pot-holes itself becomes the stream channel, while a new set of pot-holes begins to form below the new bed.

Thus it comes about that the gorge of a small river may be nothing but connected pot-holes. High up, one sees the oldest set, with nothing left of them except a portion of each side. The stream now runs through a broken line, each connecting

with its neighbors up-stream and down. Below, a new set is forming, which by and by will connect and become the brook gorge. Thus slowly, the gorge drills down through the ledge.

This only illustrates the way in which pebbles and sand in running water can drill through the hardest rock. For the most part, however, a stream does not drill; it saws. The pebbles and gravel and sand, dragged and rolled over the stream-bed, grind out the gorge directly, only in part helped by pot-hole formation. So the river cuts down into the upland like a great saw. Thus it makes itself a gorge.

But the sand-water saw can not cut indefinitely. As the bottom of the gorge gets lower and lower, the river's pitch from source to mouth becomes less and less. So the current slackens; and the cutting down of the bed becomes slower and slower till it stops. Obviously, no river can ever cut down its bed below the level of its own mouth.

That sounds like a rather simple matter—but it was not till about 1870, that John Wesley Powell, afterward head of the United States Geological Survey, working in the Grand Canyon district, first of mankind, saw all the implications of the idea, and founded upon it our whole modern Physical Geography.

Powell had already lost an arm in the Civil War, where he was a major of artillery. In the spring of 1869, being then thirty-five years of age, Powell risked his life again by running the rapids of the Colorado River, nine hundred miles in all, in a common open boat.

It really was a wild venture. The river is swift; once started, there was no getting back. The gorge, in places, is a mile deep; and its walls rise sheer from the stream. If anything happened, there would be no climbing out. Besides, if one did climb out, there was only the Arizona desert at the top, and wild Indians, who as a matter of fact did make way with several of the party. Nobody knew what was in the bottom of the great canyon, because nobody, up to Powell's time, had really explored the district, and Powell himself knew only the flat country above the river.

But Powell's great theory was already taking shape in his mind. The river, he reasoned, runs through a nearly rainless district, fed from the mountains at its source. The river is swift and is carrying sand. Therefore the river can not have falls in its course, because the sandy water will have ground off the lip of the fall. There will be boulders in the stream-bed, that have fallen off the valley walls; and there will be rapids where the

river comes down over a hard layer in the rocks. But there can not be a waterfall; and a boatload of explorers ought to be able to get through, even if their leader has only one arm. And get through safely they did, albeit with some narrow squeaks.

That was before the days of newspaper publicity. Powell, having completed one of the great feats of geographical exploration of all scientific history, sat down to write a government report on the matter and to set forth his notions concerning the geography of his district.

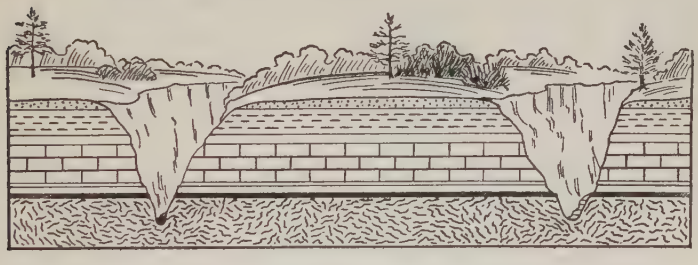
The whole plateau, Powell reasoned, has been coming up slowly until now it is nearly two miles above the sea. But the river is older than the plateau. It was there when the plateau was a low plain. There it has stayed. As the land rose, the river cut into it, keeping its bed at a good deal the same level. The land, in short, was pushed up against the river a good deal as a log is fed against a circular saw. The log travels horizontally past the saw. The plateau surface has traveled vertically past the bottom of the river.

From this reasoning of Major Powell's, at various other hands besides his own, comes the modern doctrine of "base levels of erosion."

In general, the continents are coming up; not so regularly, for the most part as did the Colorado

Plateau, but by fits and starts with long intervals between rather sudden uplifts, and not in general as wholes, but as local elevations, a few score thousand square miles at a time. So the rivers, that have been creeping sluggishly over a flat lowland, find themselves, in a few thousand years or so, high in the air, with a pitch to give them swift currents and renewed cutting power.

First, then, they cut away at their bottoms; and saw a gulch, chasm, glen, canyon, gorge, or whatever else it happens to be called locally, straight and narrow, down into the upland. The



YOUNG LANDSCAPE

The valleys are narrow, the streams cutting at their bottoms. The level upland is still imperfectly drained.

result is such a river valley as the Grand Canyon, the Yellowstone Canyon, the Niagara Gorge, the glens and chasms of eastern New York, and ten thousand others more or less like them all the world over, where a stream has somewhat lately started

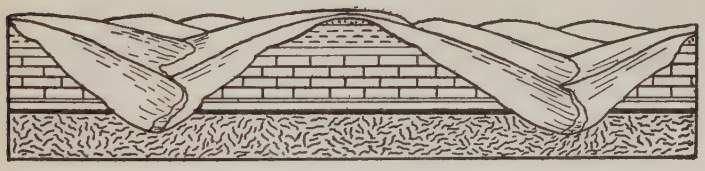
cutting on its channel floor, and is cutting down rapidly. All narrow mountain valleys are of this type; for the stream keeps growing longer, cutting back at its source into the upland, and the upstream end of a valley is always younger than the rest. In its youth, therefore, a river has a narrow, steep-sided valley and a swift current.

But the young river can cut down only to its "base level of erosion." That is to say, there is always a theoretical surface, at the level of the river's mouth and rising inland just enough to make the gentlest slope down which water will run, below which no lapse of time will enable any river to cut its valley floor. As Powell himself puts it, who invented the words "base level," there is "an imaginary surface inclining slightly in all its parts toward the end of the principal stream draining the area through which the level is supposed to extend, or having the inclination of its parts varied in direction as determined by tributary streams." On this notion of base level of erosion hangs all our modern geography.

So the young river cuts down rapidly toward its base level. But the longer it cuts, the slower. As the cutting on the bottom slows down, the valley has time to widen out at the top. Rocks fall off the valley wall, and are ground up and carried

off by the stream. Rocks weather to gravel and sand and soil, and the rain washes them down into the valley bottom, where the river works them over and along, to make bars and flood-plains and deltas, all the way to its mouth and into the ocean.

By and by—in tens of thousands of years, indeed, yet in a very short while as the earth's life goes—each valley has widened out until each just reaches the next. In other words, the original upland has disappeared, and the country is nothing



MATURE LANDSCAPE

The larger streams are approaching base-level and deepen their valleys but slowly. The valleys have broadened out until the old upland appears only as the tops of rounded hills. Every point is in some valley, and the drainage is complete.

but valleys. That is the mature stage of a river system. Most rolling country is at about this stage or a little later. There is no spot that is not definitely in some valley; but the valley sides are high enough to form rolling hills.

Beyond this stage, the valleys begin to overlap. No valley can go much deeper, being already well down to base level. But the ridges that are the

valley sides are still high—and they keep wearing down. We must, then, think of the mature landscape as made up of valleys and nothing else; and we must picture the rocks everywhere as decaying into soil, and this soil as everywhere creeping down-hill to the streams and being borne off to the sea. Thus North America is being weathered away and carried off on the average at the rate of

Old Landscape

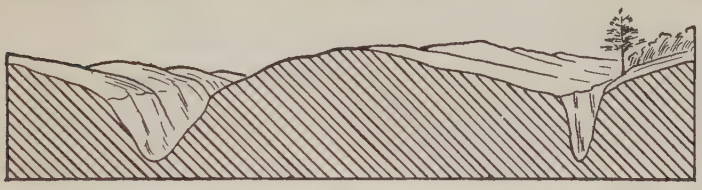
The streams have ceased to deepen their valleys, and the ridges between the valleys are worn down to low hills. In the final stage, the entire district becomes nearly flat, with only just enough pitch to carry off the water. If now the country be elevated, this nearly flat surface becomes the nearly level upland of the young stage, new and steep-sided valleys form, and the cycle repeats.

a foot in some eight or ten thousand years. But most of this average foot comes off the sides and tops of the hills, and almost none of it comes off the valley floors.

In time, therefore, theoretically, a country should wear down to its base level and become a nearly flat plain, with just slope enough to carry off the water. Practically, however, this rarely occurs—though it actually did come off for much of North America during the Cretaceous. The old age of a river system has to be enormously

drawn out; for the country is too flat for swift streams, and the soil creeps off so slowly down the gentle slopes that it buries the hard rocks and slows down their decay. Only under most uncommon circumstances does any large area ever stand still long enough to be actually "base-leveled."

Commonly, taking off the load as the country erodes away upsets the equilibrium between the



REJUVENATED LANDSCAPE

A landscape between maturity and old age has been rejuvenated by an uplift, and the streams are cutting new valleys at the bottoms of their old ones. A common type of landscape, since the earth rarely stays in place long enough for the full cycle to be run through.

high district where the weight is being taken off and the sea-floor where the land waste is being laid down. So the sea-floor sinks and the land rises, usually rather suddenly and rapidly as the accumulated strain finally gives way; always, apparently, very many times faster than any inch in a thousand years that the rivers could keep up with.

Result is that the rivers renew their youth and start everywhere cutting young valleys, usually in the bottoms of the old ones of the mature land-

scape before the uplift. That makes a sort of two-storied, gambrel-roof topography, like that of the Rhine Valley, much of New England, all of New York, most of Pennsylvania—in fact almost anywhere that one has the eyes to see it.

An extreme case is the Colorado district. Here the ancient lowland plain, that had already been worn down to a nearly flat country, went up nearly two miles. The rivers cut into it. But being in a dry district, there is much less than the normal washing in of the valley wall from the sides. So the canyon remains narrow and one of the great scenic wonders of the world. In a wet country, ten times as much material would have gone off to sea; and the valley, equally deep, might have been fifty or a hundred miles wide. Then nobody would have thought it remarkable, and it would not have given Major Powell his big idea. There, then, is one type of new-raised, two-storied landscape. There is the vast flat upland and the very narrow river bottom, only just big enough to contain the stream. The Niagara Gorge is another example of a good deal the same thing.

The Catskill Mountains and the White Mountains and the Rhine district are another type. Rip Van Winkle went off to sleep in the new, steep-sided glen that has formed since the last uplift of

New York State. If he had not been too drunk to climb the glen wall, he might have found himself in gently rolling farm country, that is the older landscape in the mature stage that was forming when the uplift occurred. That old country did not wear down to base level before the cycle was cut short, but only a little more than half-way.

The White Mountains do the same thing on a bigger scale. One climbs desperately up steep valley walls, plows over landslides, gets on as best one can with nothing better than hand-holds. But some four or five thousand feet up, so suddenly that one can almost draw a chalk-line where it occurs, the immediate landscape becomes tame. One finds oneself among little rounded mountains set on top of the high peaks. In fact, two of the highest summits in all New England are as flat on top as many an upland farm. If either were dropped down five thousand feet it would be cow pasture.

In other words, there was the old landscape, well down to sea-level, eroded to small mountains or rounding hills. Then it went up in the air, sometimes five thousand feet, sometimes no more than half a hundred. That old landscape then became a new upland. Its rivers thereupon proceeded, as rivers ever do, to cut it up into a new

landscape. The new landscape is down near sea-level and the big cities are part of it. The old landscape remains as the upland farms and high mountains, not much altered since it went up into the air. So one gets—for example in New England and in Pennsylvania—fairly deep and well-defined valleys that belong to the new erosion cycle. But the hilltops are all at about the same level, or they form a slightly rolling plain that slopes seaward. One stands on any hilltop and sees the straight skyline, that was the old Cretaceous landscape familiar to the last of the dinosaurs, into which, now elevated, the present-day valleys are being cut.

Present-day geography is the study of valley systems and their cycles of development. Whosoever will keep his eyes open can see almost anywhere all that Powell made out a half-century ago when he, first of all mankind, went through the Grand Canyon.

CHAPTER XV

ICE AGES, OLD AND NEW

THERE is one feature of the landscape that seems always to have intrigued human curiosity, from about as early as men have been curious about nature at all—the so-called "erratic blocks" or "transported boulders."

These are all over northern Europe and northern North America, down to about the latitude of New York City on one side of the Atlantic and London on the other. They occur also, still farther south, in most big mountain districts—the Alps, for example, the Pyrenees, the Caucasus, the Atlas Mountains in Africa, and the Himalayas. Moreover, they are striking objects, often as large as a house, and perched aloft on spurs and ledges where they stand out on the sky-line like the proverbial nose on a man's face. No wonder, therefore, men noticed them.

Examination proves nearly always that these erratic blocks must have been transported from some distance, because almost invariably they are

unlike the ledges on which they rest. Sometimes, indeed, when they chance to be rock of some peculiar sort, the particular spot from which they came can be located, ten or twenty miles away. Moreover, these erratic blocks are not infrequently scratched and grooved and polished, as if they had been dragged over rough ground, and the ledges under them are also not uncommonly likewise scratched and grooved and polished as if by the erratics dragged over them.

Here, then, is a neat little problem in the interpretation of nature: Given a block of stone, forty or fifty feet the longest way, into the thousand tons in weight, moved twenty miles across country and left not seldom higher in the air than the place from which it was taken, to find what did it? That problem occupied the scientific world from before the beginning of the nineteenth century up to well past its middle.

Pre-uniformitarian solutions were, of course, easy. All one had to do was to suppose that the earth's rotation had slowed down suddenly. Then, of course, all the loose material on its surface would keep on going and be shot forward like the passengers in an automobile that runs into a tree. Or if this seems unduly fanciful, there is always Noah's Flood. One has only to suppose vast and violent

Erratic Boulder
(Glacial.)
Photograph by the Geological Survey of Great Britain

waves, traveling twenty times as fast as waves have ever been known to travel, twenty times as high as waves have ever been known to be, and they could wash a thousand-ton block twenty miles. If they could not, why then, we have only to imagine our waves forty times more violent instead of twenty. If only we may imagine causes, we can explain anything by them.

But along about the time of the American Revolution, this ancient practise of imagining causes began to go out of fashion both in the natural and in the political world. A hypothetical sea wave capable of moving a thousand-ton block in the interior of North America or two miles up in the Himalayas impressed that highly skeptical period as about as well founded as the Divine Right of Kings. So out both notions began to go at not far from the same time.

Curiously, here in America, the first man to suggest a better theory of erratic blocks seems not to have been any professional geologist or any college teacher of geology, but a plain business man, a cotton manufacturer of Connecticut, by name Peter Dobson.

Dobson was digging his cellar for a new factory, and like a thrifty Yankee taking heed that his servants earned their pay. His cellar, as most

cellars in New England do, went into the so-called boulder-clay, hard-pan, or till, a very compact soil, that has to be dug out with a pick, and that is a confused mixture of clay, sand, pebbles, and boulders. The boulders are sometimes ten feet in diameter, and they are often scratched and grooved and polished like the erratic blocks. They are, in short, merely buried erratics that run in size from the dimensions of a small house down to a man's fist or the end of his thumb. But they are all essentially alike. That is to say, they all are unlike the rock under them, and they all show signs of having been dragged across country. They are so abundant that all the rough stone fences of the world are built of them, except those where the stone has obviously come out of a neighboring ledge. Probably ninety-nine per cent. of the farm walls of New England are built of these till boulders.

Dobson observed these boulders with Yankee shrewdness. They were, he noted, "worn smooth on their under side as if done by their having been dragged over rocks and gravelly earth in one steady position;" and some of them in addition showed by the character of their scratches and furrows which side had gone first, for a projecting hard crystal protected the softer parts behind. The only way, opined Mr. Peter Dobson, that all this

can be explained is by forgetting all gigantic tidal waves and supposing the boulders, both the till boulders and the perched erratics, to have been moved by ocean currents frozen into the bottom of icebergs. The bergs would, naturally, drag and grind. Thus the boulders would be scratched and polished.

Dobson, in 1825, wrote to Benjamin Silliman, Professor of Geology at Yale, editor of the *American Journal of Science,* and on the whole the most influential American man of science of his time, setting forth his observations and his theory. Silliman paid no attention. Dobson waited some years, observed still farther, and then wrote to Reverend Edward Hitchcock, D. D., who was the great man in natural science at Amherst, as Silliman was at Yale. Hitchcock also ignored the matter. But in 1842, finding that the great Sir Roderick Murchison, addressing the Geological Society of London, commended the cotton mill owner as "the original author of the best glacial theory . . . a previous acquaintance with which might have saved volumes of disputation on both sides of the Atlantic," Hitchcock had Dobson's letter printed in the *American Journal,* and himself adopted all Dobson's views.

The trouble was that in spite of Hutton and

Lyell, geology had not really become "uniformitarian." Whoever noted a fact that he could not explain, simply called it "a mighty convulsion of nature" and let it go at that. Other men, alas, do about the same thing still.

This old notion of the erratic blocks and the boulder-clay as ice-drifted—a notion which, by the way, still lingers among the unscientific—really had a deal of fact in its favor. For one thing, present-day icebergs of the North Atlantic, floating southward in the sea, actually do carry rocks and gravel. They are the broken-off ends of the Greenland glaciers, and they have picked up no small quantity of Greenland soil; which they now, as they melt, are dropping on the Atlantic floor. If such an iceberg ran aground, it would naturally scratch the surface that it hit.

Moreover, there is undubitable evidence that much of Europe and North America, that is now dry land, has been under water, and that lately, indeed long since the beginning of the human period. One sees everywhere in the United States north of the latitude of New York, abundant signs of flood-levels, one and two and even three hundred feet above anything that the rivers attain to now. There are obvious river deltas standing high and dry, that in cases not a few prove by their

structure and slope that the rivers that formed them ran in the opposite direction from the streams that flow past their bases in this year of grace. There are obvious beaches high up on the side of hills. There are great banks of water-worn gravels miles away from any present-day streams. There is positive evidence from such deposits that the ocean has recently—as geologic time goes—been up the St. Lawrence, around by way of Lake Champlain, and through the Hudson Valley, so as to make New England an island. In fact, all through New England, the graveyards are on these old "diluvial" gravels and the race-tracks are on the ancient deltas.

The iceberg theory of the erratics and the till did, then, fit in nicely with a great deal that can be proved concerning water-levels high above everything that we know to-day. It was, moreover, an easy inference to suppose that this great flood-time over much of North America, much of Europe, and as it turns out much of Asia as well, is identical with the Noachian Deluge of Genesis.

But the trouble with the iceberg theory of the drift is the enormous quantity of the latter. There are erratic boulders everywhere. The boulder-clay, all over northern United States, forms virtually continuous sheets hundreds after hundreds of miles

across. It runs five and ten and twenty feet thick, and locally it piles up two hundred feet. All this mass is so full of scratched stones, that any one who has his eye in, can unearth a specimen with his boot-toe in a few moments and almost anywhere. Moreover, the ledges under the till are universally grooved and polished and smoothed and rounded, with the polished surfaces acres in area and the grooving sometimes a foot deep. Certainly they were most remarkable icebergs and a great quantity of them that could account for the hundredth part of the facts that in the course of time came to light.

Nevertheless, that theory of Dobson and others held pretty generally, well up to the middle of the nineteenth century. It was not at all on scale with the phenomena that it had to explain—but there seemed nothing else that would explain the phenomena at all.

To be sure, that same John Playfair whom we have already encountered just before 1800 playing Huxley to Hutton's Darwin, had pointed out that not icebergs in the water but glaciers on land are the obvious sort of frozen water to grind pebbles across a ledge or set perched boulders high on a hillside. The idea, however, did not take. Glaciers form in mountain valleys. Much of the drift—in

some districts, all of it—is in a flat country. Besides, augmented glaciers must mean a colder climate—and there is nothing about anything of the sort in the Bible. It is one of the anomalies of human reason that men will admit sudden stoppage of a spinning earth or mountain-high tidal waves to sweep inland a thousand miles, and yet draw the line at a ten-degree drop in mean temperature.

That, nevertheless, is precisely what men did, and the notion of valley glaciers, larger than now or formed where none now are, to supplement the work of floating ice, came in only slowly and against resistance. Edward Hitchcock, D. D., for example, after being President of Amherst College, and then Professor of Geology there, and then State Geologist of Massachusetts, became also, from 1857 to 1860, State Geologist of Vermont. He, in his Vermont report, delivered the opinion that "what we call drift phenomena in New England was produced by glaciers such as we have described as once connected with the Green Mountain range. But the main features of the drift we impute to icebergs and ice-floes as the continent was gradually sinking beneath the ocean." Hitchcock, as befitted his New England environment, was not the man to adopt precipitately any new idea.

The man who really solved the problem of the perched blocks and the boulder-clay was Louis Agassiz, beginning in 1836, when, not yet thirty, he was already Professor of Natural History at Neuchâtel.

Neuchâtel is in the Jura, less than a hundred miles from the source of the Rhone—and the Rhone starts in a glacier. Agassiz had a friend, Charpentier, who was the outstanding advocate of the glacial theory of the drift, in the sense that he had gone farther than any one else in advocating the former extension of the Alpine glaciers, even to maintaining that these had aforetime actually reached out beyond the mountains and dropped down erratics and till over the Piedmont plains. That the Alpine glaciers had once extended farther than they reach now was beginning to be somewhat widely held. That they ever extended as far as Charpentier imagined, few persons were ready to believe—and Agassiz was not one of them.

But Agassiz belonged to the new school in natural science, the school that eschews speculation and argument, and gets after the facts. It was Agassiz's special service to these United States that he, probably more than any other single man, forced American science-teaching into the way that the best of it follows now. So Agassiz and Char-

Scratched Glacial Pebble

From the till of central New York.

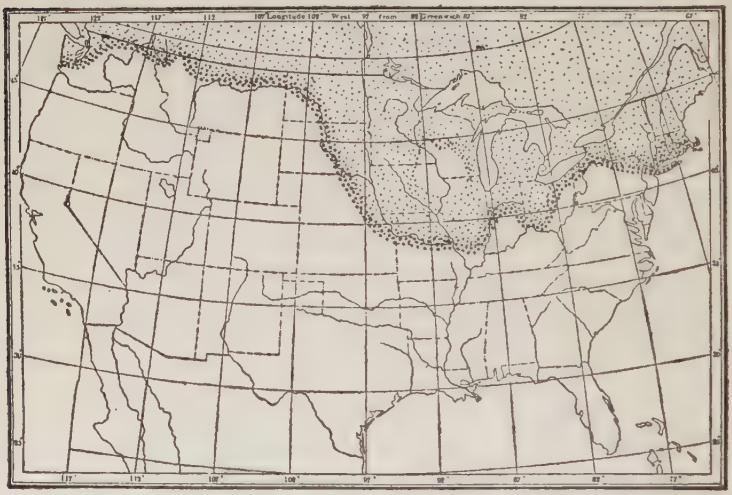
Photograph by R. S. Tarr, Cornell University

pentier put some weeks of the summer of 1836 into tramping the flanks of the Rhone Valley, while Agassiz explained to Charpentier where Charpentier was quite wrong in thinking that the glaciers of Swiss mountain valleys ever extended down on to Swiss lowlands.

Charpentier, however, so far failed to get the worst of the argument, that by the end of the summer Agassiz was objecting to Charpentier's theories on the ground that his friend was altogether too timid in pushing his ideas. Not only, maintained Agassiz now, had the valley glaciers of the Alps flowed down as far as his friend demanded; but they had, he now opined, advanced far beyond anything that Charpentier had dared imagine. By the summer of 1837, when the national scientific society met at Neuchâtel, Agassiz, who was their president that year, fell to telling them in his official address that, so far is rafting by icebergs from being the chief agency in transporting the drift, with glaciers subordinate, that he was then persuaded that icebergs had had virtually no part at all. Instead, the glaciers had done it all—not mere valley glaciers such as they had seen out their own windows, but vast ice-caps, greater than that which now lies over Greenland. "Siberian winter," said Agassiz, "established itself for a time

over a world previously covered with a rich vegetation, and peopled with large mammalia, similar to those now inhabiting the warm regions of India and Africa."

Buckland was Agassiz's first important convert, and for a short while his only one. That conversion

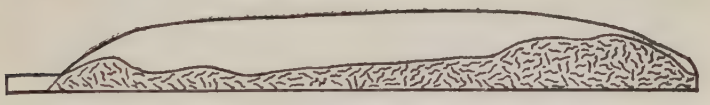


Drift Area of the United States and the Great Terminal Moraine

was characteristic of Buckland's quality. Buckland was one of the leading British authorities on the various superficial deposits which it was the fashion of the day to attribute to Noah's Flood, had invented the term "diluvium" for the drift, and had written an important volume called *Reliquiæ*

Diluvianæ or Observations on Organic Remains Attesting the Action of an Universal Deluge. Buckland was also a clergyman—he later became Dean of Westminster—and he was the outstanding advocate in the English Church of Noah's Flood as a geologic agent and the corroboration of the Scriptural account by the testimony of the rocks and their fossils. Moreover, he was more than fifty years old.

For all that, as soon as Buckland got the report of Agassiz's highly revolutionary theory that would upset much of the work of Buckland's life and show him to be wrong on just those opinions



PROBABLE SURFACE OF GREENLAND UNDER THE ICECAP

The center is completely buried. At the margin, the ice flows out between the mountain peaks as glaciers and floats away as icebergs.

on which rested his reputation in his church and no small part of his chance of preferment therein, off he posted to Switzerland to see Agassiz in person and be taken over Agassiz's ground. He saw at once that Agassiz was right—and said so. By 1840, he had converted Lyell. By 1842 Darwin had come round. But Sir Roderick Murchison still stood out for the iceberg doctrine. By a de-

cade or two after the middle of the century, the scientific world agreed that an ice-cap like that of Greenland had covered half of Europe, with—as we now know—three more, each a mile thick, over more than half of North America.

So there had been an Ice Age, that lasted until long after men invaded Europe, an Ice Age, in fact, in the last stages of which we ourselves still linger, for there are glaciers on most of the high ranges of the world, and both Greenland and Antarctica are still buried under ice-caps, where was a very decent climate when man—or at least a tool-using animal—first appeared on earth. The signs of this Ice Age are all about us, so that he who runs may read. The question is whether this last Glacial Period is the only one in earth's history; or whether, on the other hand, the same boulder-clay with its scratched pebbles and its grooved ledges underneath, has marked also other geologic horizons in the still more remote past.

The latter seems quite decidedly the case. The great coal period toward the end of the Paleozoic, which gave us all our eastern coal, and Europe likewise all of its, seems to have been, on the whole, a rather warm and probably rather moist time. At least, it was pretty certainly not especially either cold or dry. But right after it came a time that

was dry in some parts of the earth, and cold enough for glaciers in others.

There is a patch of rock, for example, in the Boston district that looks exactly like the common glacial drift—scratched pebbles in typical boulder-clay, laminated silts that show the annual banding as the glacier froze up in the winter or softened in the spring. But everything is now solid rock, obviously very old, and the somewhat uncommon fossils associated with it prove its age to be late Paleozoic.

The same sort of thing occurs also in Brazil and Argentina. There is more of it in Germany, of the same geologic age; and apparently a little in England. There is a great deal in India, the old till coming down to sea-level well inside the tropics, and resting on just such a smoothed and scratched and polished surface as we find almost everywhere under the recent drift. South Africa shows the same phenomena, at the same geologic time. Australia shows this best of all, with single glacial beds two hundred feet thick, interstratified with marine beds and coal seams, as if the climate had changed back and forth from warm to cold several times—as we know it did in the last Ice Age, that Agassiz was the first to make out.

So there was another great Ice Age back about

half-way to the beginning of detailed geologic history, that left patches of glacial drift in every continent, affected the earth from Tasmania to Germany, and brought the ice down on to the plains of central India within eighteen degrees of the Equator. Florida, be it observed, does not quite touch twenty-five. Moreover, fossil trees outside the glacial deposits, show annual rings like our trees to-day in regions of cold winters.

In short, our latest Ice Age that put the "hardpan" over much of Europe and North America for the laboring man to dig out with pick and shovel, so far from being the only Ice Age that the world has known, was not even the most extensive. The late Paleozoic ice-caps covered, apparently, something like twice the area of the Pleistocene.

Moreover, there was another Ice Age down at the bottom of the Paleozoic, twice as far back therefore in geologic time as the late Paleozoic one. Patches of this old till appear in Norway, China, and Australia. In China, in the latitude of northern Florida, there is a hundred and seventy feet of obvious glacial till, scratched boulders and all, and over it lie sea-floor muds containing lower Cambrian trilobites, the whole now altered to hard rock.

So much for all theories of the earth that make it out to be a cooling globe!

CHAPTER XVI

THE CHRONOLOGY OF AN ICE AGE

As soon as it transpired that there have been great ice-caps a mile or two thick over most of the more interesting parts of two important continents, the public, quite naturally, wanted to know how long ago it all was, and in particular how long it has been since the ice went off.

That is a question to which, the moment one stops to think, one sees that there can not be any possible answer. The great Pleistocene ice-caps have really not departed yet. There is one over Greenland at the present moment, that is nearly a thousand miles wide, nearly two thousand miles long, and nobody knows how thick because nothing else shows anywhere except just along the margin. The Antarctic ice-cap approaches ten times the size of the Greenland. So there are as large ice-sheets on earth now as there ever have been; only there are not so many of them, for it took three separate continental glaciers to span the width of North America, and the one that lay over Europe was never more than about four times the

area of the one that lies over Greenland now. So the Ice Age is not over yet; and when we ask when the ice went off, what we really mean is when it went off the district where we live. Wherever that spot may be, the region to the south cleared many centuries earlier, and the region to the north was still ice-bound many centuries afterward. There is no date, then, for the end of the Ice Age as a whole. One can give dates only for particular spots.

Quite arbitrarily, then, the end of the Pleistocene and the beginning of recent geologic time is taken to be the date at which the ice left the region of Ragunda in north-central Sweden, and the big ice-sheet of Europe split into two parts. That was about 6500 B. C. But the ice had cleared from the Stockholm district by 11500 B. C., or five thousand years earlier. So the ice over the peninsula backed away about one mile in each twenty years, and the time it took to disappear was not so very different in length from the period that has elapsed since.

That it is possible to fix geologic dates for the Scandinavian Peninsula much more accurately than for any other part of the earth so far, is due partly to the remarkable ingenuity of certain Swedish geologists, but quite as much to sheer good luck.

Sweden is, to begin with, very far north. Christiania has the latitude of the tip of Greenland. There are plenty of towns well inside the Arctic Circle. Sweden, in short, has a heavy winter snowfall, and long summer days to melt the snow away. Its summer-winter cycle is therefore uncommonly well marked.

The result is that the clay deposits both at the heads of the fiords and in the fresh-water lakes tend to show marked seasonal lamination. The spring floods bring down and deposit a fine silt. Then in the summer, when the streams are lower, the deposit is a finer and "fatter" clay above the silt, interbedded with more silt after each hard rain. In the fall and winter, when the streams are frozen, nothing settles out but the finest clay. Next spring comes the silt again. Thus each annual layer is distinct, like the annual growth rings of a tree where the growth is rapid in the spring, slackens in the summer, and stops in the cold weather. In a Swedish clay-bank, then, one may count the annual layers as accurately as one counts annual tree-rings elsewhere.

But Scandinavia has, pretty generally, been rising, slowly but on the whole steadily, since the end of the Ice Age. The weight of the ice jammed it down. With the ice off, it has been coming up.

This, naturally, tends to drain the old ponds and to bring up the old clay-banks at the fiord heads, to levels where they can be seen conveniently, dug into, smoothed off with a trowel, and have their annual layers counted. It does not make any difference whether these layers were formed in glacial lakes ten thousand years ago, or at the heads of fiords since the invention of printing. There they are for anybody to count. The only difficulty is that the deposits of the last few hundred years are still under water. So the count is uncertain at the start. Fortunately, there are a few trees three centuries old, so that it is only a question of time before the missing clay-layers are pieced out with tree-rings and we have a continuous count from present known dates back indefinitely. Thus far, the count spans about thirteen thousand five hundred years.

There is, naturally, a certain error in this counting of "varves" in the clays, as the Swedes call them from their word for iterated layers. There will sometimes be early springs that afterward turn cold, and so make one year's deposit look like two. There will sometimes be cold summers that make two years' deposit look like one. But such anomalies are rare, and the error they introduce is only of the order of one year to the century. So we now have time intervals before human history actually

STRIATED BED-ROCK WITH TILL.

Shore of Lake Michigan.

Photograph by I. Russell

known more accurately than many a date afterward. As for Archbishop Usher, whose dates in the margins of our Bibles have been taken for two hundred years as no less inspired than the Scripture itself, one can, by picking variant Biblical manuscripts, shift his dates ten centuries.

The man who first worked out this device for making geologic dates absolute instead of relative was one Baron Gerard De Geer, of Stockholm, who began his field-work toward the beginning of the last decade of the nineteenth century. Work of the same sort in America belongs only to the current decade of this, and little has been done thus far outside New England and New York.

A Retreating Ice-Tongue Forms Annual Layers in Standing Water at Its Foot

Baron De Geer brought over a party of Swedish geologists in 1920 to try out his methods on American deposits, and one of his pupils, Dr. Ernst Antevs of the University of Stockholm, spent the summer of 1921 counting up the "varves" of the Connecticut River from Hartford to St. Johns-

bury, with a half-dozen enthusiastic Americans in his train. Unfortunately, New England, instead of rising like Sweden, has been sinking. So there is no bringing down the count here into historic times. Moreover, Antevs or De Geer have hit upon no device for correlating certainly American with Swedish dates. We know that the ice went off New England at somewhat the same time that it went off Europe, because the apparent age of the drift is about the same, the animals and plants in corresponding deposits are about alike, and the new valleys that the rivers had to make after the ice departed, because the drift had blocked their old ones, are in about the same condition as those of Europe. But there may be a thousand years difference in deposits that look the same age, and there is still no way to discover just which clay layer in the Connecticut was put down during the same summer with a known layer above Stockholm. Precise timing across the North Atlantic, as we correlate dates in United States history with those in British, is still to come.

So Antevs picked an old glacial pond near Hartford, Connecticut, that had been filled by the wash from the retreating ice, dug down as far as was convenient, called that lowest varve, number 3001, and started counting up through the deposit, up-

stream on the river, and toward the present in geologic time.

It really takes one's breath away to see what can be made out by this method, concerning events of ten millennia ago. Varve 3001, for example, of date in the ten thousand B. C., was a rather cool year. That particular pond got seven millimeters of spring and summer silt and eight millimeters of winter clay. The next year had about average weather, and the pond filled up twenty millimeters altogether, the clay again a little ahead of the silt. The 3003 year had about a normal winter with eleven millimeters of clay deposit. But its summer was uncommonly hot, and the freshets from the melting glacier washed in sixteen millimeters of silt, twenty-seven millimeters in all. Next year, the summer was correspondingly cold, the ice melted less than usual, the freshets were small and only five millimeters of silt washed in. In general, the finer winter clay is about the same in amount year after year, becoming finer and more regular as the ice-front gets farther and farther away. The difference between different years shows mostly in the summer wash. Varves may run a half-inch thick for a year or two, then jump to a whole inch, for one hot summer, only to come back the year after to the normal size. Or the wide varves may

continue two or three years and then drop. But when an ice-dam bursts up-stream, that summer's varve may jump from the normal half-inch to two or three feet. Moreover, a single old pond-floor may count straight up a thousand or fifteen hundred annual layers, and be the weather record for a period almost as long as that covered by the annual rings of Californian big trees.

So it went. The year 3016 in the Connecticut Valley had quite the hottest summer for nearly fifty years. Then came two scorchers a year apart with a more than average hot time between. After that, barring a rather uncommon summer here and there, nothing happened for an oldest inhabitant to brag about till the year 3224. There was another warm spell around 3265; and then 3444 beat all records for four centuries.

But evidently, hot and cold and average weather a summer through is a much larger matter than adjacent ponds or neighboring river valleys. When the ice melted fast in the Connecticut, it melted fast also in the Hudson and the Merrimack. A cool summer showed about equally in all three. Number 3051, for example, was the coldest for eleven years one way and ten the other. Then the temperatures rose steadily to 3055, which was the hottest since 3016. Then it dropped. Then it rose

again in 3057 to the same height as two years before. Next it took a long drop, rose for two seasons, and fell to the remarkably low record of 3061.

All these temperature changes, based on the amount of melting ice and the resulting deposits a few miles beyond the ice-front, are accurately plotted on long strips. If the plotted curves from two neighboring ponds or two near-by rivers are alike for ten or twenty years, then we know that the varves also correspond in date. We come to the end of our count in one clay-bank. We pick it up again in another farther up-stream where the deposit runs a little younger.

Thus Antevs and his disciples worked along up the Connecticut Valley, and over into the Hudson and the Merrimack. The Connecticut series extends from 3001 to 7399—forty-four thousand years for the Connecticut Valley lobe to retreat from Hartford to St. Johnsbury, not quite two hundred miles. At that average rate, it should have taken five times as long, or more than twenty thousand years to get all the ice off Labrador. The point is that it probably took at least as long for the ice to go completely after it started, as there has been elapsed time since the last bit went. So there is no real answer to, when did the Ice Age end? unless one first decides that it is to end where.

But, after all is said, we don't really know that the Ice Age has ended, nor that the ice is not shortly coming back. There were five well-marked interglacial epochs in Europe, with about as many not so well marked in North America, when the great ice-caps melted off to leave nothing more than the valley glaciers that we pay money to see now, when osage oranges grew at Toronto, elephants and hippopotamuses invaded Britain, *Homo neandertalensis* chipped flints at the door of his cave, skinned his cave bear with knives shaped from its own bones, ate bison and oxen and dogs and horses and elephants and rhinoceroses and pigs, and enjoyed on the whole and for centuries at a time quite as warm a climate as we his supplanters have now. So there have been at least five interglacial times, alternating with six advances of the ice, that were as warm as times are now, and lasted as long as time has been since the great ice-cap last went off. We may be through with the ice for another geologic age, and be headed for such another time as that of the Age of Reptiles, when cold-blooded saurians lived inside the arctic circle, and Greenland grew maples, oaks, and magnolias. Or on the other hand, we may only be not far from the middle of a sixth interglacial age, with the ice destined to come back in another ten thousand years, to make

WHERE ICEBERGS ARE BORN

Ice front of the Muir Glacier, Alaska.

Photograph by H. F. Reid

Europe uninhabitable and the Sahara a cool and pleasant and well-watered country, the seat of a coming civilization somewhere about 11930 A. D.

Nobody can tell. There was an Ice Age about as early as we have good evidence of any sort of climate. There was another about half-way along through geologic time. There was a third just the other day, only some ten thousand years ago, that is not over yet. Anything may happen next. All one can say is that the world has been here a long time, and that it still goes on a good deal as it always has, as Hutton said more than a century ago, "with no trace of a beginning, and no prospect of an end."

"And, everywhere, in all the record of the rocks,
Time and to spare for all that Time could do."

CHAPTER XVII

THE CLIMATES OF GEOLOGIC TIME

One tends to think of an Ice Age as very cold. It need not be anything of the sort. Greenland, for example, is ice-capped still. But there is a district in northeastern Siberia, partly on the warm side of the Arctic Circle, larger than all Florida, where the mean January temperature is as much lower than that of Greenland on the edge of its ice-cap as winter Greenland is colder than Florida itself. In fact, within the area of the United States, in Minnesota and the Dakotas, right along regularly in the winters, the little children put on their mittens and trot away to school at temperatures that run about the same as those off the Greenland coast where the Eskimos are spearing seals on ten feet of sea ice, or looking inland over snow-fields piled up a mile deep.

What makes an Ice Age, then, is not cold winters, but cool summers. There is no ice-cap over Siberia, because long before the winds have brought the moisture of the ocean that far inland,

all the water has been frozen out of them—"it is too cold to snow." What little snow there is promptly melts away in the twenty-four hours a day of sunshine, in a temperature like that of northern Scotland. The coldest place in the world, where the thermometer averages zero the year around, is not ice-capped. Greenland, which is ice-capped, runs twenty degrees warmer the year through. But its summers are actually cooler than around the "cold pole" of the world.

Apparently, then, an Ice Age is, in part, a local affair. Given a district fairly mountainous so that the high country cools the air, given the right run of ocean currents to bring warm water offshore, and the right run of on-shore winds to bring the moisture inland, given besides an even winter climate just cold enough so that there is ample snow but no rain, with a mild summer climate that does not melt the drifts away, and there have to be glaciers in that district, no matter what the rest of the world is doing. The Alps have glaciers now, in the latitude of Minneapolis and Portland.

So, after all, there is no reason to suppose that the earth's average temperature during the last great Ice Age was more than about ten degrees colder than it is now. Ten degrees mean annual temperature is the difference between Sitka and

Portland on one side of the continent, Cape Cod and Cape Hatteras on the other, Missouri and Louisiana in between. Not cold, but heavy snowfall, makes an Ice Age. A drop of three degrees would probably put back the glaciers of northern Scotland.

On the other hand, there were the hot times—also, apparently, more or less local—when temperatures ran about as much higher than they do now as they ran lower in the last Ice Age. We are, then, now betwixt and between as to climate, "lukewarm and neither cold nor hot." But the earth's bad times have been very much shorter than its good ones; so that, on the whole, the globe, for the most part, has been kinder to her children and a cozier place to live on than anything that our human race has known. We men came at a bad time, encountering ice-fields changing to deserts. Our anthropoid forebears' Alma Mater was a far kindlier earth.

For the Tertiary in general, especially perhaps some of its earlier divisions, along through the times when our own forebears were getting ready to climb down out of the trees, or had already done so and were fairly on their land legs, must really have been a very delightful time over most of the world. The big mountain ranges were not up, to

cut off the ocean-winds, make deserts on their down-wind sides, glaciers toward the sea. The Mediterranean, twice as wide as it is now, went through into the Indian Ocean. Asia was cut in halves by a wide strait. Africa and South America were whittled away variously. The world, in short, was off and on, six or eight comfortable land-masses from the size of present-day Australia up, with many groups of islands as the Malay Archipelago in our times. So the ocean water circulated freely. There were no deserts; and nothing that an oldest inhabitant nowadays would think of as a winter. Grapes grew in North America inside the Arctic Circle; breadfruit trees in Oregon; figs in Colorado. Crocodiles swam the streams of South Dakota.

Yet the Age of Mammals started with a cold time, almost another ice age. Before that, through the Age of Reptiles, it had been warm—as warm as during the Tertiary, albeit with two cold spells. But there was another Ice Age earlier, that strung along from the late Paleozoic well into the Triassic. Another marked the beginning of the Paleozoic that was at least as long and as severe as the one that froze out early European man. Besides these, there was at least one more, still earlier, too early for enough fossils to date it by. In all, there have

been four well-marked Ice Ages, with three more cold times that just missed putting on big ice-caps over the higher northern lands. In fact, cold times and warm seem to have alternated somewhat regularly throughout known geologic time, though luckily the cold times have nearly always been far shorter than the warm ones, and only four of the coldest have been actually glacial.

There are, in short, characteristic and wide-spread glacial deposits as late in geologic time as the first proper men. But there are also equally characteristic and wide-spread glacial deposits that are earlier than the dinosaurs, still others that are earlier than the first known fishes, and others still that are earlier than any proper fossils. In between any two of these cold times, have come longer or shorter interglacial epochs that, on the whole, have been about equally warm. So the earth as a whole is growing neither cold nor hot. It simply alters back and forth, as from summer to winter and day to night, without really getting anywhere. Climatic change, also, exhibits "no trace of a beginning and no prospect of an end." That, too, is "uniform."

How far an Ice Age may be only a matter of local conditions, one may guess by looking at the two sides of the North Atlantic. The Gulf Stream

comes up along the coast of Florida where the earth is spinning eastward nearly a thousand miles an hour. Naturally then, the Gulf Stream water is also flying eastward with the spinning earth ten times as fast as anything there is except an airplane. But a point on the Arctic Circle travels eastward only half as fast, a mere ten times as fast as express trains go. So the Gulf Stream, working poleward but still keeping something of its tropic momentum, outruns the spinning earth, flows diagonally across the Atlantic, and floods with warm water the whole shore of western Europe and almost half the length of the north coast of Asia.

Compare, then, the two sides of the North Atlantic. The British Isles, for latitude, just match Labrador. But they by no means match Labrador for climate. A few wretched fishing villages on one side of the ocean, mirror the world's great cities on the other. Much of Sweden and most of Norway—civilized lands these thousand years—are as far north as Baffin Island and the Land of Little Sticks northwest of Hudson Bay, that are not even habitable. So much does the run of one ocean current affect the climate of lands otherwise alike.

But the Gulf Stream itself is fed from a great current of hot water that flows westward across the Atlantic, under the Equator, pushed along by the

friction of the westward-blowing Trade Winds. South America juts eastward in a vast triangle that brings eastern Brazil nearer the longitude of London than of New York; and that projection of South America eastward is enough south of the Equator so that it throws virtually the whole of that warm current north, rather than half-and-half or south.

Behold, then, the effect on the climate of the two ends of the earth. Tierra del Fuego is a dreadful country, where a handful of half-starved and wholly-frozen savages barely keep the breath in their miserable bodies. But Tierra del Fuego is nearer the Equator than Bonnie Scotland, with Edinburgh just about the latitude of Cape Horn. That is what the shape of one land-mass does to another region a quarter of the earth's circumference away!

One does not think of Stockholm and Christiania as especially far north, nor that great and ancient city that a while ago was called Petrograd. All three are in about the same latitude, sixty north or a trifle less. But sixty south is half-way from Cape Horn to Antarctica, almost down to the South Orkneys, where the only vegetation is an occasional patch of coarse grass and there are no land animals.

Annual Layers in Glacial Clay, Last Ice Age

Connecticut River opposite Hanover, New Hampshire

Annual Layers in Slate, Paleozoic Ice Age

Newton Center, Massachusetts

Photographs reproduced through the courtesy of *R. W. Sayles, Department of Geology, Harvard University.*

Norway, long a highly civilized country, extends well within the Arctic Circle, and summer tourists go in comfort to seventy-one degrees north to see the sun at midnight. But seventy-one degrees south is in Ross Sea, where the icebergs are a mile across and a quarter-mile thick, floating two hundred feet above the water. Not till 1899 did the first ship drop anchor inside the Antarctic Circle and the first of mankind, so far as known, winter through an Antarctic night. But Hammerfest in Norway is as near the Pole, a busy harbor for coastwise trade, where reindeer flourish, birches grow, perpetual ice lies only on the mountains, and the inhabitants go sea-fishing all winter. Hammerfest, more than a thousand miles farther from the Equator than Cape Horn, has the mean January temperature of Nebraska.

But that eastward projection of Brazil need not have been there. In fact, it was not there during the Age of Reptiles. That same land-mass put twenty degrees farther north, would throw the whole Atlantic Equatorial Current the other way, and make Scandinavia and the British Isles a frozen wilderness. One can easily figure out a distribution of land that would put back the Pleistocene ice-caps on to both. Evidently, so far as ice-caps are local affairs—as they certainly are in part—

local conditions will also, in part, explain their advances and retreats. We have no special reason to think that the earth's average climate has grown warmer within historic times. But all the ice of the world is melting back. Even the great Antarctic Ice Barrier, that stands in places twice mast-high, which those who believe the earth is flat take to be its outmost rim, even this has shrunk southward thirty miles since Ross, shortly after 1840, first charted the great sea that still carries his name.

Even so, there still remains the Glacial Period late in the Paleozoic, that put the ice inside the tropics on both sides of the equator. Obviously, no change in the relation of land and water, no rise of mountain districts, no run of ocean currents, alone, will account for that. One must turn in addition to some sort of general cause that affects the whole earth at once.

One hopeful path is by way of alterations in the atmosphere. All the earth's heat, substantially, comes from the sun. But only about half of that which reaches the outer limits of the usable air, ten miles or more above our heads, ever gets through to warm us. The other half is stopped on the way and lost. A different atmosphere, that would let more heat through, or stop more, even though the change were only ten per cent., would

make vast alteration in the climate of our little planet.

On the other hand, the earth, when the sun is not shining on it, is always radiating heat and cooling off. Even at midday, under a tropic sun, the earth radiates back into space, part of its heat as fast as it comes in. So the temperature, whether under the equator or at the pole, always tends to hang in the balance of profit and loss. What counts is not so much the amount of solar heat that comes in, as the proportion that the earth holds and stores up.

But it so happens that the sun's radiant energy runs to shorter wave-lengths than does the earth's. It happens, also, that short waves go through the particular atmosphere that we actually have more easily than long waves do, as blue glass lets through the shortest waves of visible light, stopping the longer red. But our atmosphere might have been like red glass and stopped the sun's radiation instead of the earth's. A greenhouse acts on the same principle: literally a trap to catch sunbeams. Part of the sun's energy goes through the glass on a short wave-length, but can not get out again on a long one. That difference warms both the greenhouse and the world.

But the glass of our cosmic greenhouse is the

carbon dioxide of the air—less, indeed, than a thirtieth of one per cent. of the air's volume, but immensely efficient in differentiating wave-lengths. So the carbon dioxide in the air lets the sun's heat in, more than it lets the earth's heat out; and the earth, in consequence, warms up. The sun shines on the earth only half the time. The earth shines on space always. But thanks to the constitution of the air, the earth's shine goes the wrong way and is partly stopped.

Evidently, then, more carbon dioxide in the air—as much, let us say, as we are all used to indoors—while it would tend to diminish the energy that the sun would send through to the earth's surface, would diminish still more the earth's own loss; and the globe would warm up. On the other hand, with less carbon dioxide in its atmosphere, the earth would get more heat, spend more, save less, and cool off. Changes in the amount of carbon dioxide—let us say, from half what there is now to twice as much—might in no small part account for warm climates like that of the Tertiary, cold ones like the several ice ages, and intermediate ones like that we have now.

Common impression is that the carbon dioxide of the air is a nice balance between that given off by animal lungs and that taken in by the leaves of

green plants in the sunlight and split into oxygen and carbon. Really, however, the animals do not count. They merely eat a portion of the plants that otherwise would decay, and so come to the same thing a little more slowly. We animals, so to say, merely catch a small part of the carbon as it goes by. We can not live without the plants; but the plants would get on exactly as well without us.

What we do, especially those of us who live in salt water and have thick shells and skeletons, is to lock up vast quantities of carbon dioxide as lime. The limestones of the earth, mostly animal remains, contain in the form of carbonates, many hundred times as much carbon dioxide as the air ever does. If they gave one per cent. of it back to the atmosphere, nobody knows what the effect would be on earth's climate everywhere.

But every proper volcanic eruption pours forth vast quantities of carbon dioxide. Evidently, then, toward the end of a long period of volcanic activity, the earth's atmosphere should be appreciably different from that at the beginning. But a long quiet time should let the plants store away carbon as coal and the animals store it away as lime, till the air comes back to normal. Volcanoes, therefore, should tend to warm the earth—not directly,

but by trapping the sun's heat. When plants and animals flourish, their remains being preserved, they tend to lock up carbon dioxide, cool the earth, and work themselves out of a job.

Water vapor also acts in a good deal the same way as carbon dioxide, letting through the short radiant waves from the sun and stopping the longer waves from the earth. But the water vapor tends to freeze out of the air, to fall as rain or snow. That sets up a vicious circle climatically. The colder the air gets, the less moisture is there in it to blanket the world and keep us all warm. So the air, that is mostly warmed from the earth, gets still colder, and so becomes still less efficient. Warm air, on the contrary, tends to get still warmer; and after that, being wetter, warmer still. So each cold wave and each warm one grows by what it feeds on. Moreover, an ice-cap, once started, tends to form clouds that cut off the sun and bring down the snow. Weather, in short, like many another aspect of this strange world of ours, once started keeps on going quite beyond reason.

There, then, in the peculiar diathermancy of water and carbon dioxide, is probably one efficient cause of long-term swings of the earth's climate back and forth.

Still another may lie in the circulation of the

ocean water, quite independent of any run of surface currents and vastly more important than all surface currents combined.

As things are now, the ocean water is heated under the tropic sun, expands, flows poleward at the surface, cools off in high latitudes, sinks to the ocean floor, and comes back again as a slow creep of ice-cold layers along the bottom. Then it comes to the surface once more near the equator, is again warmed, and again flows away. Thus the equatorial heat is carried to the colder parts of the earth. How efficient this is under favorable conditions, the Gulf Stream proves abundantly.

But the equatorial sun does not only warm the ocean water, it also evaporates vast amounts. What remains tends, therefore, to be a stronger brine, heavier and therefore disposed to sink. Conceivably, the ocean water under the Equator might gain more density by evaporation than it lost by expansion. In that case, the warm equatorial water would drop down to the ocean floor and creep slowly poleward, to come to the surface, still warm, far to the north or south. So the surface currents would be cool and the bottom currents warm, instead of the reverse as now. That arrangement, evidently, would warm high latitudes and cool low much more efficiently than does the present circu-

lation. This should tend to make a somewhat even climate everywhere, such as the earth did enjoy before the last Ice Age. But the balance between being expanded by heat and being made denser by evaporation is always delicate. A little change one way or the other, would speed up the circulation of the ocean water or slow it down. Not very much alteration would reverse the circulation completely. So there is some reason to think that our present-day circulation, warm water on top and cold below, is really unusual; and that the normal interchange runs the other way. Thus we seem to have long warm eons with the ocean water flowing equatorward at the surface then short cold times, like this in which we live, when things go wrong.

Finally, the sun itself is known to be a variable star.

There are thousands of such stars in the sky. Among them are the short-period variables which every few hours or every month or so, suddenly double their light—and presumably their heat, if we had any way of finding it out. There are also long-period variables, like *Mira,* in the constellation Cetus that has been watched now for some three hundred years, and seen to change brightness in a vaguely regular swing, timed about once

to one of our years, and to be at some times ten thousand times as bright as at others. There are also temporary stars or *novæ,* that are caught nowadays sometimes two or three a year, and may be highly irregular variables whose maximum has been seen only once in the short while men have been on earth. *Nova Persei* in 1901, in four days, jumped its light twenty thousand times; and then within the year, dropped back irregularly, with at least two considerable recoveries, to just about what it had been before. If that star's light is any measure of its heat, and if that star has any planets as our earth, inside half a day after things began to happen, the water must have begun to boil out of the oceans! The day after that, the rocks began to melt!

Luckily our own luminary is better behaved. It has the familiar eleven-year sun-spot cycle, that varies irregularly from seven to sixteen years. What longer period cycle there may be, can be determined only by waiting round a few thousand years to see.

In short, then, there is no doubt that the earth has, for many million years, been subject to slow swings of climate, back and forth from warm to cold; and that several times at least, the cold spells have been severe enough to count as veritable Ice

Ages. Nobody, however, knows the cause of such changes in the past nor what to predict for the future. Many causes have been suggested. Several of these, most probably, are concerned. Apparently, there are certain general forces, which operate some at one time and some at another. Then there are local causes. As these all happen to fall together or apart, there are mild climates, and Ice Ages, and times between, with a certain vague rhythm betwixt the two extremes.

CHAPTER XVIII

LIFE WITHOUT FOSSILS

When all is said, the only way to understand what this earth has been like during the long stretches of the past is to look round and see what it is like now. Geology is neither more nor less than a succession of geographies; and at least since the early Paleozoic, when the fossil record fairly begins, there seems never to have been a time when some part of the ancient earth did not precisely match some part of the modern one.

To be sure, the animals were different. But even so, an ichthyosaurus seen from a liner's deck would look to a landman's eye exactly like any one of the smaller whales. Only a big-game hunter, seeing at a distance a herd of triceratops, would be able to tell these great reptiles from so many cows—unless one of them took to scooping out a nest and laying eggs. Even a naturalist can not distinguish certain of the Lower Paleozoic brachiopods from those that are alive now.

But the moment one tries viewing the past in

the light of the present, one sees forthwith that there can not be any truth at all in the wide-spread impression that such animals and plants as we know as fossils are any fair average sample of the creatures that have inhabited the earth. Nature has been no museum curator selecting specimens to fill out gaps in anybody's information. Nature has not been any Noah, taking "of clean beasts, and of beasts that are not clean, and of fowls, and of every thing that creepeth upon the earth . . . two and two . . . male and female," to give us a complete and correct picture of everything that has been before us in the earth. On the contrary, we actually do find one species fossilized by uncounted millions, while another species, dwelling side by side with the first, may be known only by an occasional footprint or by the fragment of a single tooth. So careless has Nature been of the feelings of any paleontologist.

Evidently, then, we know the creatures of the past a good deal as they possess hard parts—wood for the plants, skeletons and teeth for the animals. But vast numbers of plant species have no wood in them, or too little to count. Of these, therefore, we can, of necessity, know virtually nothing. Vast numbers of animal species have no bones or teeth. Of these, also, we can know nothing in detail—a

track, perhaps, where one of them crawled across the mud; a streak of black shale colored by their indistinguishable remains. We know, indeed, vastly more about extinct animals than extinct plants; but we know little about even the animals until some of them had evolved thick shells and hard teeth. Four-fifths, probably, nine-tenths quite possibly, are lost off the beginning of the history of life on the earth merely because soft creatures, after they have lived, have nothing to show for it.

But even wood is not so very durable—as most householders learn to their cost. Wood that does not fall into a swamp or get preserved in salt water, might about as well not be wood at all for all the record it will leave. Even animal bones and shells, barring swamp water and the sea or the remote chance of getting sealed up in the stalagmite of a cave floor, do go to pieces very fast. The wonder is, not that we have so few well-preserved relics of the past, but that we have any at all.

What counts, really, more than most else, is where the creature chanced to live.

One sees, for example, at the seaside, vast quantities of seaweed mantling the bare rocks, and vast numbers of animals—some of them with hard shells—dwelling along with it. But none of that

abundant life is ever going to be fossilized. The fact that the rock is bare means that no mud is being laid down to bury anything. All that teeming life, therefore, will be ground up by the waves and leave no trace.

Even more is this the fact on a beach. Every pebble against its neighbor, every sand-grain against its fellows, is a little mill, that grinds not so slowly and does grind exceeding small, everything that grows thereabout or is washed ashore, the moment the breath of life is out of it. One sees bricks and glass ground down, first to rounded pebbles, then to fine mud, and all within the memory of living men. What chance, then, has any creature on a beach to be kept fossil for posterity?

In fact, when one comes to think over what is actually happening now, one sees instantly that throughout the geologic past the one place where fossils can get preserved on any considerable scale is bound to be on the offshore mud-flats, from high-tide level down, let us say, two or three hundred feet. There, where the sunlight penetrates, life is abundant. There dwell creatures with shells and teeth. There also is more mud continually being laid down to bury over and preserve in the salt water, whatever creatures live on the bottom or

Ordinary Glacial Till, Last Ice Age

Newtonville, Massachusetts.

Indurated Till, Now Pudding-Stone, Late Paleozoic Ice Age

Squantum Head, Boston Harbor

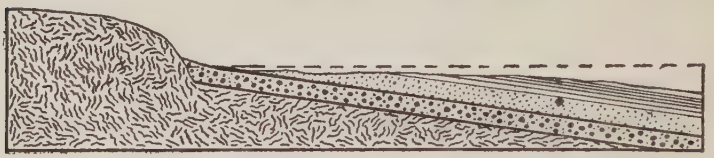
Photographs reproduced through the courtesy of *R. W. Sayles, Department of Geology, Harvard University.*

sink from above, uneaten, to lie on it. We know, therefore, most of all about the animals of the shallow seas. But the sea plants, floating their weight, have no need to make themselves wood, and we know little about these.

But even shell-fish, preserved by the million in offshore mud, will not give us a single recognizable fossil if the sea-floor happens to be coming up. For in such a case, obviously, the soft mud that has formed down in the quiet water has to come up through the waves. If by any chance it escapes being cut to bits by them, then, being above high tide, it promptly washes away in the rain. Only under most exceptional circumstances will any fossiliferous deposit on a rising sea-floor ever survive to leave its record for the future.

Only a stationary sea-floor, then, or a sinking one, can preserve a fossil record. But since the land rarely remains still for long, practically we have the fossil record only of such sea-floors as chanced to be sinking while the record was being made, and were buried deeply enough, and stayed down sufficiently long, to become well hardened before coming up again to the dry land where we see them now. Just such a region of slow-sinking with in-washing of layer on layer is that long trough from Nova Scotia down to Alabama that

is now the Appalachian Highland. The earth buckled along that line. The rivers and the waves brought in sand and mud and gravel to fill the trough. The floor of the great trough sank under the load just about as fast as the land-wash filled it in. So we have to-day shales and sandstones and conglomerates and limestones, and coal seams, single formations sometimes a thousand feet thick,



FOSSILS ARE BEST PRESERVED BY A TRANSGRESSING SEA

As the beach eats into the shore, older portions are buried under later offshore deposits with their characteristic fossils. The beach then becomes the "basal conglomerate" that usually marks the beginning of a new portion of geologic time. The outer part of each stratum tends to be older than the inner.

but all for the most part laid down in no deeper water than men go fishing in now. Another such great trough runs through from the Gulf of Mexico to the Arctic, or at times, stops by the way; and there are various others, for the most part smaller and sometimes only a few miles across, all over the south and west of North America, and all the other continents as well. Often these troughs are so shallow as to form swamps and give us coal. Sometimes they are above sea-level, and become

filled with river silt laid down as fan-deltas or lake floors. But in general, all continuous and at all satisfactory fossil records come from lands just above or just below sea-level, that sank and stayed down for some time after the fossiliferous deposit was formed.

It follows from this that at least half the fossil record, in each district, is bound to be absent. Pudding-stones and the like will not have fossils anyway. Sandstones somewhat rarely do. Mud-stones and limestones have them profitable only in that half of the deposits that came on a sinking ocean floor. So it happens that successive formations give the impression of discontinuity of species. The record tends to be lacking when the land is coming up. Moreover, as the depth alters, the plants and animals migrate, for each species is fitted to one set of conditions only. These two facts account for the sudden appearance of species, for just that discontinuity in the record on which the older geologists based their opinion that species are created.

Offhand, then, one would suppose that sea-creatures would be vastly better known than land forms; and that shore-dwelling sea things would be better known than creatures of the open sea, for example, whales. This is only partly the fact. We

do, indeed, know little about the past life of the open sea, because only the shallow-water deposits have ever come up to the light of day to become land rocks. What there is in the others, men probably will never know. Still it does not follow that we must always know more about sea-life than about land creatures. The more recent sea-floor deposits are still down under water, and only our descendants, a million years from now, will know what is in them. We know the sea-creatures of the ancient seas, not those of times nearer our own.

In general, then, there is a shift of our information from land to sea as we go back in geologic time. For the late Tertiary and the Pleistocene, just before the rise of our own stock, we have the record of swamps and tar-pits and cave deposits, of lake floors and the flood-plains of rivers, even of kitchen refuse, graves, and lost stone tools. But all such are always close to the surface. As the land wears down, they depart with it. In general, back of the Age of Mammals, we have little in the way of land deposits besides such swamps and river deltas and lake floors as chanced to get buried under sea-floor deposits and preserved.

In the Upper Paleozoic, we have conspicuously the coal, old swamps that had the uncommon fortune to be dropped gently below sea-level without

being cut to pieces by the waves as they went by. Not often has that happened in the past. Below the Middle Paleozoic, the record is mostly sea things. The land deposits have eroded away. The fresh-water remains are nearly or quite all gone. We have the record only of the shallow sea. If we may reason from analogy, the Lower Paleozoic lands were covered with vegetation just as the lands are now. The fresh-water stream and lakes had their inhabitants like ours to-day. But we have no record; and we know not what these plants and animals were like.

Just here comes much of the trouble in constructing genealogical trees down in the Paleozoic. We may, or we may not, find the sea-dwelling ancestor; but if the missing forebear lived in fresh water, the chances of locating him are very slim. If he lived on land, there is no chance at all.

There, in particular, is the crux of the insoluble problem: Who were the ancestors of the Vertebrates? We can run our line back pretty certainly to primitive fishes of the Ordovician. But there we stop. We do not know whether the forebears of those fishes were threadworms, or jointed worms, or ostracoderms, or something more like balanoglossus. But the reason why we do not know—and probably never shall find out—is that that myste-

rious ancestral fish, whoever he was, pretty certainly lived in fresh water. The earliest known fishes appear suddenly. Apparently, they evolved in the rivers and then swam down to the sea. Beyond that, what shall men ever know?

In between the Cenozoic, where for certain land forms such as the elephant and the horse, we have an uncommonly satisfactory record, and the Paleozoic, where the sea-creatures are best known, comes the Mesozoic, the Age of Reptiles. Here, curiously but logically, we have the land record for the low country, but not for the upland. The great reptiles, in the days when they ruled the world, were mostly creatures of the swamps and the wet grounds, living on much the sort of plants that grow—on a smaller scale—in wet places now. For the upland vegetation, the grasses and the broad-leaved trees—in short, the angiosperms—had not yet evolved and do not appear in the record until the Age of Reptiles is nearly over. So we have preserved quite satisfactory quantities of reptilian remains, all from the low country.

Yet even here one sees how fragmentary may be even the best of fossil records. The famous Connecticut sandstones show footprints of twenty or thirty different species of land dinosaurs, hundreds of a single sort, from the size of a robin up,

with hardly a bone to correspond. Indeed, for years after these "bird tracks," as they were at first thought to be, had been studied minutely, sorted out, named, and preserved in museums, not a single bone was known to go with them. Even now, a few of the museum restorations have had to be helped out with material from Colorado and Bavaria. But for the footprints, then, we might know almost nothing of all that abundant reptilian life of the eastern United States. So much is the preservation of even dinosaur bones at the mercy of small accidents.

But along with this somewhat full record of reptilian life in the swamps and lowlands and the shallow water, salt and fresh, there are also vague hints of an abundant upland life both animal and plant. Certain small mammals are known, mostly from teeth and lower jaws, half-reptilian creatures, some of them, that may or may not have been ancestors to such mammals as ourselves.

We really know very little about them. They lived in the upland. Their remains are most scanty. The creatures themselves were small, the size of rats. For a guess, they were something like our present-day Insectivora—shrews, moles, hedgehogs, and the like. But they may very well have laid eggs like the duck-mole, *Ornithorhynchus*.

There simply is not enough material to settle any such questions.

So we have much the situation for the ancestor of the mammals that we have for the ancestor of the vertebrates. The latter was, apparently, a fresh-water form—and we do not have fresh-water deposits from the Lower Paleozoic. The former was an upland creature—and we do not have upland deposits from the Mesozoic. Men can read only the records given them.

In the same way, we know little about the ancestry of the higher flowering plants, such as now make up our forests and carpet our fields. Most of these nowadays are upland forms. Very few indeed, even now, will grow in salt water. So we have not their remains, and we can not make out directly what their history has been. They appear suddenly, just as the lower vertebrates did before them and the higher mammals afterward. Doubtless all three had long histories. But those histories are not in print.

In the same way, we know curiously little about the early birds. Birds do not, for the most part, live in caves. They do not fall into ponds. They do not get mired in swamps. So we have two specimens only of the earliest of them, *Archæopteryx* that was half reptile, with teeth and a tail

long enough to wag. Then comes a vast gap, and two more sorts of toothed birds turn up, both aquatic, one of them a diver with powerful legs and no wings at all. Of the land birds to match these, not a trace remains. Only in the Age of Mammals do the modern sorts appear—gulls and herons and flamingoes and eagles and owls and quails and ostriches—as if they had all flown down out of the sky. There is simply no record of where they came from.

We have the same trouble trying to run down our own pedigree. The great apes that were our forebears frequented upland woods. There were not many of them anyway, for creatures living on nuts and fruit can never compete in numbers with those vast herds of ungulates that live on grass—our own western bison, for example; thousands in a single herd. An ape is too intelligent to fall into some sorts of trouble. He has hands to pull him out of some others. Altogether, then, one should not expect to find many fossil anthropoid species. As a matter of fact, the number of species is small, hardly more than a single dozen, and the number of individuals of some of them smaller still. We men are in the same boat with the vertebrates and the mammals and the birds and the higher flowering plants. We simply do not know who our grandparents were.

Alas, a fossil record, good or poor, once made, by no means endures. The ground water is always circulating everywhere—and water is a highly efficient solvent, especially when hot or flavored with acids. So the ground water keeps dissolving out the fossil record from below about as fast as it forms on top. Result is that the earlier parts are absolutely wiped out.

One gets a hint of this in certain marbles. One sees vague markings that are obviously the remains of shells. One knows, moreover, that marbles and limestones are made up of animal remains. But not a shell fragment shows the least detail that any mortal man can make out. When the process of recrystallizing goes a little farther, not even a trace remains of animal shells in a formation that was originally nothing else.

The fossil record, therefore, cuts off suddenly at the bottom of the Cambrian. Above this, in certain strata at least, lies the record of a teeming shallow-water life—crustaceans, brachiopods, jointed worms, sponges, jellyfish, corals, snails, clams—that really does not differ especially from the same sort of thing in modern seas.

The trilobites, for example, extinct now, were quite as well equipped for the battle of life as modern crustaceans are. They had eyes, both

simple and compound. Some of them had rudimentary eyes, as if they were descended from ancestors that had proper ones, but had lost them through taking to deep and dark water or burrowing in the mud. Here, then, at the very beginning of any fair fossil record, is a creature that is as far along in its evolutionary progress as any creature at all like him has ever gone.

As for the mollusks, along with snails and clams which are somewhat primitive in organization, there are, in the Upper Cambrian at least, others of the chambered nautilus type, that are counted as the highest of their class. So far, almost at the beginning of the life record, had the progress of life already gone. Evidently, we have only the last chapters of a long story, the last fifth, possibly no more than the last tenth, of the history that we hoped to read.

Of plants, we know still less. There must have been plants; for animals, ultimately, have to feed on them. But from the Cambrian survives no hint of any land vegetation whatever, and only a few and most obscure signs of sea things. We have, in short, to start our history with everything important already here. We do not know where things came from. We know only how they have altered since they arrived.

Below the Cambrian, everything suddenly fails. There are a few vague worms and brachiopods, together with some other creatures even less to be made out. Curiously, the one sort of animal really known below the Paleozoic is a crustacean, that is about as highly evolved as our modern lobster. So small a portion have we left of the record of the whole course of things.

Nought, then, can be less profitable than speculation about our own human ancestral tree beyond the Ordovician fishes. Down that far, we do have record—albeit with inconvenient gaps, not, to be sure, very large. But below the fishes the tale is any man's guess: there simply is no evidence.

We may know more when the rest of the earth has been explored as thoroughly as certain portions of Europe and North America already are. As it is, the evidence from paleontology, and the evidence from all the other sciences concerned, stops at just about the same place.

CHAPTER XIX

THE BEGINNINGS OF THE WORLD

We can go back, then, in geologic time, to the beginning of the Paleozoic Age, following all the way detailed and certain evidence. We find at the beginning of the Paleozoic a world essentially like the world we know. The climate is about the same, not warmer than the tropics now nor colder than the poles. The earth is divided into land and sea, as we know because we have the sea-floors formed of the land-wash and old shallow-water; offshore deposits, such as mark the sea border now. The plants, we know little about—there is no reason to think that they differed in numbers of individuals or numbers of kinds from plants to-day, or that they failed to cover the land and the sea-floors, and to float about in salt water and fresh, where there was room to grow and sun to shine on their leaves, precisely as they have ever since. Seed-time and harvest have not failed these hundred million years.

As for the animals, we have no record of either land or fresh-water forms—but that seems to be

entirely the fault of the record, not the living things. Apparently, there were of animals also as many different kinds as now. For if virtually all that we know to-day had not arrived on earth then, about an equal number, alive then, have become extinct since. Apparently, the total mass of creatures has always been about the same. There have always been, so far as the record goes, all the living things on earth that could possibly find space to live. The significant thing is that although we do not actually know any vertebrate from the bottom of the Paleozoic, every other great branch of the animal kingdom was represented, and that by creatures as high in structure as those like them now.

Below the fossiliferous rocks of the Paleozoic lie barren wastes, a pile of rocks, twisted and mashed and altered almost out of recognition, that is apparently as thick as all of the rest of the earth's rocks combined and blankets the globe everywhere under land and sea. Its upper limit is the bottom of the Paleozoic rocks. Its lower limit, nobody knows. Anciently, it was interpreted as the original crust of the globe, created in the beginning or frozen when the molten globe cooled off.

Yet, apparently, most of this is only greatly altered stuff of the same old familiar sort that we

see everywhere in younger formations. There are limestones that may once have been animal remains. There are dark shales that seem to be colored with the carbon from creatures once alive. There are what were certainly ordinary surface lava flows such as might come out of Mauna Loa or Vesuvius any day. There are also typical beach conglomerates—abundant ones at that. If the world was especially different in "Archean" time, there is no known evidence to prove it.

Back of the record of these ancient rocks, that pretty certainly contained abundant fossils once but have lost them since, lie still vaster stretches of pregeologic time, when the earth was a planet and nothing more, and the problems set the inquiring mind belong rather to astronomy than to such sciences as have to do with earth. But astronomy has no fossil record; and what astronomy has to say concerning past or future of any planet must needs be highly speculative. Moreover, there are conventionally only nine "planets" in the sky, of which only five besides the earth show any sort of helpful detail to guide anybody in guessing at the earth's own youth. Inevitably, then, what we know about our planet's history from the record, and what we surmise on theoretic grounds, have very different validities indeed.

Our present-day astronomy, so far as it especially concerns the family of planets of which our earth is by no means the most important to anybody except ourselves, has really come to us in three different stages.

The old "Ptolemaic" astronomy, with its planetary heavens inhabited each by its proper sort of angel and the Creator of it all sitting on his great white throne that rests on the *Primum mobile,* broke down during the century or so that centers on 1600, under the attack, among others, of Copernicus, Galileo, and Tycho Brahe. Theirs was essentially a problem of motions only. The earth, they made out, follows such and such a path. They did not consider why it moves at all; and even Kepler, who was the first of mankind to define the earth motions accurately, opined that a holy angel, obeying the behest of the Almighty, carries it round the sun.

Then came Newton, in 1687, and got himself into seven and seventy different kinds of trouble by disposing of the holy angel and treating the earth's motion as a problem in "force." Then once more, in the first half of the nineteenth century, various persons, of whom Joule is probably the most familar by way of giving his name to the unit, took up the general problem of the conservation of

energy. After that, scientific thinking shifted from pounds and kilograms to ergs and joules and kilowatts; and no theory of the earth's past would hold water that did not figure the energy involved.

The old Nebular Theory of Kant and Laplace, that everybody is supposed to know all about, belongs to the second stage of planetary astronomy, when one had to think only of the forces involved in motions, and did not have to bother about where the energy came from in the first place nor what became of it afterward.

There were various forms of this. Some presupposed a cold nebula; some a hot one. But they all united in assuming a highly diffused "green" nebula, of enormous volume, that gradually fell in on itself, started to rotate, left behind portions of itself—usually as rings that afterward became planets—and finally became the solar system that we know. They were most ingenious theories. They also sounded highly convincing, in the days before the Conservation of Energy.

With that doctrine, however, about a century ago, they all promptly broke down. Visible gaseous nebulæ seen in the sky are obviously not rotating. If they were, they could not possibly have anything like the shape that they visibly have. But our solar system does rotate. The planets go round

the sun. The satellites go round their primaries. The sun itself spins on its own axis, and each of its planets follows its example. The energy of all these rotating and revolving bodies can be calculated accurately. So, too, can the energy of each separate one; and, therefore, the total energy of the hypothetical planetary ring from which it was supposed to have been formed. The figures do not come out in the least as they should. Our own earth, for example, actually has nearly two thousand times the momentum that it ought to have according to that old Nebular Theory. On dynamical grounds alone, even if there were no others, that whole Laplacian Nebular Theory may be dismissed from everybody's mind as one more prescientific speculation that has not the least present-day support.

With it will go the rest of the picture that usually accompanies it—the globe of hot vapor, first cooling to liquid, and then forming a crust that we still have as the granites and related rocks; the atmosphere, charged with all sorts of irrespirable gases, raining boiling water on a red-hot crust; oceans of dilute acids that ate into the new-formed rocks like vinegar on marble; clouds that for ages hid the sun; and all the rest of that engaging but absurd picture that one still encounters in non-

scientific writings. There is not the slightest direct evidence that anything of this sort occurred. The ancient speculation from which the whole of it is derived has long departed from scientific ken.

In scientific circles, therefore, for the last half-century, that old Nebular Hypothesis has given way to other doctrines, among them, of late years, the so-called Planetesimal Theory. For scientific people are after all precisely like the rest of us, and can no more resist—most of them—the urge to speculate where they can not prove than other men can.

It turned out when the sky came to be photographed pretty generally, and was seen to be full of various sorts of things whose light suits a gelatin film better than it suits a human eye on the same telescope, that after all has been said, the "green," gaseous nebulæ are not nearly as common as the "white" ones that are at least partly solid or liquid. Moreover, these "spiral" nebulæ are already flat disks, very much the same shape to start with as the flat solar systems into which they are imagined to evolve. Besides, they virtually always have denser masses at their centers that might well be incipient suns, and they have also various-sized knots in their long, coiled, spiral arms that may well be on the way to become planets and their

satellites. Moreover, certain of them have been found to be rotating very much as a solar system derived from them would finally have to do. Altogether, therefore, a spiral nebula rather than a gaseous one, seems nowadays a vastly better cosmic egg from which to hatch out a theory of a pregeologic earth.

On the other hand, of the hundred and twenty thousand spiral nebulæ that have been estimated to be within the range of less than the largest telescopes, the smallest actually known is too big to make a solar system less than some thousands of times larger than the only one we know. But, of course, there may be others, yet undiscovered, of the same sort, but small enough to account for us. Moreover, of some thirty thousand spiral nebulæ already photographed, not one shows the least sign of evolving into anything else. Surely, if spiral nebulæ do alter to solar systems, some few of them ought to be detected on the way!

Beyond this, however, the new Planetesimal Theory is absolutely "tight." It fits all known facts. It conforms to all dynamic requirements. It is, of course, only a highly speculative theory, by its very nature quite beyond any rigid test. But within those limits, it is good science.

One supposes, then, a spiral nebula, not too

large, already rotating as spiral nebulæ are known to do, and having already formed in it a central sun-like mass, and with the right number of smaller planet-like masses in its coiled arms. It becomes possible, starting with these postulates, keeping strictly within what is known of the behavior of masses of matter, to reconstruct in a great deal of detail what *might* have been the history of our earth long before its recorded history in the least begins.

One supposes, then, the planetary-knots revolving around the central sun, each in its own orbit, conforming to the familiar laws of gravitation, momentum, and the rest. Naturally, the big masses pick up the little ones. So the big knots keep growing still larger as the smaller ones fall in on on them—planetoids of all sizes from the largest we know now, down to rocks the size of a great public building or a small cottage or a man's head or a grain of dust or a free molecule of gas. "Planetesimals" is the general name for all such stuff. Planetesimals are still falling in on our earth, dust size, ten and twenty millions a day, to make the little shooting-stars that one sees every few minutes every clear night. In the meteor showers of 1833 and 1866, the Leonids rained down on the earth all night long, "as thick as snowflakes in a

storm." Once in a while, a bigger planetesimal comes through the atmosphere without burning up with the friction, and we have a meteorite, that roars and flashes across whole states, and that somebody picks up, occasionally still hot, and sells to a museum. The sky is pretty well cleared up now. But we still have the belt of planetoids between Mars and Jupiter, thousands in number, that seem never to have found any convenient larger body to fall in on; and we still have Saturn's rings that are millions upon millions of planetesimals, none more than fifty miles across, some probably no more than dust particles, and all going round too fast to fall in on anything. Apparently, our earth started about the size of Mars, that is to say half its present diameter and an eighth of its present mass, and has built up slowly to its current size as it has swept up the sky in its sphere of influence. It grows no longer, except very slowly, because there are only minute planetesimals left to be added on.

That iron nucleus of the earth, then, which we know to be there because of the way the earthquake waves run through the earth's body, is not far from being the original planetary knot which was the original earth when the solar system was a spiral nebula—if it ever was. From that, the world has built up, pulling in by its gravitation out of inter-

planetary space, the rest of its mass, and all its air and water. So the earth started small and cold and dry and airless. It has grown in size. It has picked up water and air. It has become warm enough in spots to melt up some small portion of its rocks and squeeze them out as lavas. But all theory aside, there is not an atom of direct evidence that the earth was ever any larger, or much warmer, or wetter, or enveloped by a denser atmosphere than at this punctual instant. It may have been all these things. But there is no evidence whatever for any of them.

There is, however, even under this Planetesimal Theory the further problem, how fast matter in the sky fell to bombarding the earth, and how large the masses were that landed on it. If the planetesimals were small—not so different on the whole from our present-day shooting-stars and meteors—and if they sifted in slowly, then the earth grew only slowly; and life may have begun on it when it was as small as Mars, and the first beginnings of life—if there are any remains of it left—may be buried down a thousand miles under the present crust. We know the top of the Pre-Paleozoic rocks. We do not know their bottom. That bottom may be half-way to the earth's center—the earliest rocks that ever had fossils in them and were formed as strata are formed now.

On the other hand, if the original planetesimals that built up the earth were the size of the little planets that now revolve around the sun just outside the orbit of Mars and bear the names of sundry little Roman gods and human cities and the wives and sweethearts of various astronomers, and if these little planets fell in on the little earth in a great shower, then it is highly probable that the celestial bombardment heated up the earth much hotter than it is now. One need not suppose that the earth ever actually melted, still less that it was ever gas. But a planetoid five hundred miles across can not fall out of the sky, traveling some seven miles a second—which is a dozen times faster than a cannon-ball—without heating the target where it hits. Enough of these, coming fast enough after one another, might well soften both the earth's crust and their own substance that they add to it. Conceivably, the earth might melt clear through. Whether it did or not is something that the earth's crust nowhere certainly records.

One must, in short, distinguish sharply between the old and quite erroneous Nebular Theory, according to which on the one hand the earth *must* have been molten, and must have possessed an atmosphere quite unlike that of the present time; and the newer Planetesimal Theory, according to

which the earth certainly started cold, but *may* perhaps, during times of especially lively bombardment, have warmed up to a higher temperature than living things can stand, but certainly did not have any such gas-laden atmosphere nor any such acid-charged oceans as the early geologists used to imagine. It may be that life on the earth is new compared with the earth itself. Possibly, life here began only after the globe had grown rapidly to its present figure, heated up, and then cooled down.

But all this is only speculation. We do not really know—we have really very little evidence to suggest—that our old earth has ever been especially different, except in size and the kind of living things on it, from just what it is now. All kinds of earths that are not like the one we know are astronomy and speculation, not geology.

Geology is always the science of such rocks as the wayfaring man can look at for himself and understand.

THE END

APPENDIX

APPENDIX

THE GREATER DIVISIONS

CENOZOIC (Quaternary)	*Recent*	From the present time to the last recession of the ice from Europe and North America.
	Pleistocene	The Ice Age in Europe and North America. Vegetation modern in type.
CENOZOIC (Tertiary)	*Pliocene*	"The Age of Mammals." From the beginning of the Ice Age to the appearance of the higher Mammals. The western coal in part.
	Miocene	
	Eocene	
MESOZOIC (Secondary)	*Cretaceous*	"The Age of Reptiles." Trees mostly conifers until the sudden rise of modern vegetation. Most of the western coal.
	Jurassic	
	Triassic	
UPPER PALEOZOIC	*Permian*	From the rise of the great reptiles to the first abundant fishes. Trees mostly conifers, ferns, and horsetails. The eastern and European coal.
	Carboniferous	
	Devonian	
LOWER PALEOZOIC	*Silurian*	"The Age of Invertebrates." From the early fishes to the first abundant fossils. Plants presumably abundant; but no land vegetation known and only scanty seaweeds.
	Ordovician	
	Cambrian	
ARCHEOZOIC and PROTEROZOIC		Called variously, all or in part, *Pre-Cambrian, Archean, Huronian, Laurentian, etc.* Duration probably five or ten times as long as all succeeding time. Living creatures probably abundant but all record lost until near the end.

APPENDIX

OF GEOLOGIC TIME

Neolithic man in Europe. Cro-Magnons to present-day races.

Paleolithic man in Europe. Neanderthal and other races not *Homo sapiens*. Culmination of mammalian life. In North America: mastodons, various elephants, llamas, camels, tapirs, giant sloths, saber-toothed cats, extinct horses.

Pithecanthropus

Eolithic creatures doubtfully human. Many anthropoid apes now extinct. Four-tusked and other primitive elephants. Horses approach modern forms.

European monkeys. Long-chinned elephants. Three-toed horses.

Rapid introduction of primitive placental mammals. Elephant-like creatures without trunks. Four-toed horses. Extinct mammals of the Paris Basin.

Last of the dinosaurs and pterosaurs. The toothed-birds. Modern (bony) types of fish. Mammals, few, small, and primitive.

Culmination of the dinosaurs. Earliest flying reptiles. Earliest known bird. Few and small non-placental mammals.

Rise of the dinosaurs, icthyosaurs, and plesiosaurs. Mammals reptilian or doubtful. Giant amphibians. Reptiles with amphibian and mammalian characters. Dinosaur tracks of the Connecticut Valley.

A period of deserts and glaciers, with much extinction of species. Early reptiles, some with mammalian characters.

Earliest amphibian remains, some gigantic, all primitive. Numerous insects. No fishes higher than sharks and ganoids. Trilobites vanishing.

"The Age of Fishes," all of primitive types without bony internal skeletons. Fringed-finned ganoids with amphibian characteristics. Ostracoderms. Trillobites and eurypterids. Tracks probably amphibian. The "Old Red Sandstone" of England.

Fishes. Trilobites and eurypterids. Scorpions.

Earliest known fishes. Abundant invertebrates.

All eight branches of the animal kingdom represented except vertebrates. Trilobites and eurypterids dominant. A glacial period at the base.

Animal remains very rare, mostly from Arizona, Montana, and Ontario, and mostly crustaceans allied to eurypterids, sponges, worms, brachiopods, and a doubtful seaweed.

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